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Missoula Valley air pollution study

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MISSOULA VALLEY AIR POLLUTION STUDY

By

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MISSOULA VALLEY AIR POLLUTION STUDY

Summary

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The Missoula Valley Air Pollution Study encompassed several broad areas of research. The general goal of the research was to define and quantify air pollution problems in the Missoula,Montana area and to attempt to determine some of the effects of these pollutants.

During the summer ambient air monitoring of hydrogen sulfide and sulfur dioxide were undertaken. Eighteen hydrogen sulfide samples (11 percent of the total hydrogen sulfide samples) registered values over the State Department of Health standards (30 parts per billion (ppb)) The highest hydrogen sulfide concentration recorded was 209 ppb. This sample was collected near the settling ponds of the Hoerner - Waldorf Corporation Kraft Process pulp mill, located west of Missoula. The ambient air sulfur dioxide concentrations were relatively low. None of the sulfur dioxide samples collected violated State Health Departemnt standards. The highest sulfur dioxide concentration recorded was 58 ppb. Sulfur dioxide was detected both near the pulp mill and in the city. Background hydrogen sulfide and sulfur dioxide levels were determined in areas outside the valley. Background hydrogen sulfide levels were less than 7 ppb and the sulfur dioxide levels were less than 5 ppb. These values seem to agree with background data from other locations.

Periodic monitoring for hydrogen sulfide and sulfur dioxide was also conducted during the fall of 1972. New pollution abatement equipment was installed and operating intermittently at the pulp mill during this time. In general a decrease in hydrogen sulfide concentrations and an increase in sulfur dioxide concentrations were detected. The highest sulfur dioxide concentration detected was 190 ppb near the pulp mill

The chemical composition of rainwater in the Missoula Valley was also determined since air pollution can also effect the rainwater entering an ecosystem. The pH (hydrogen ion concentration) and the sodium, calcium, and sulfate concentrations in the rainwater were determined. The pH of the rain samples was nearly neutral (pH=7). Normal rainwater is slightly acidic (pH=5.7) and rainwater over much of the Eastern United States is quite acidic (pH=3.5 - 5.0). The sulfate, sodium, and calcium concentrations found in the valley were nearly four times as high as the concentrations in outlying regions. Hence, an unnaturally high concentration of chemicals is being added to the Missoula Valley Ecosystem through the rain.

The contribution of road dust to total particulate levels was also determined and high volume particulate sampling for chemical analysis was undertaken. The road dust study team determined that while the suspended particulate levels associated with unpaved streets were extremely high, the actual number of particles was low. The particles from unpaved streets are generally large and have a rapid fallout rate. The high volume particulate sampler used for chemical analysis of particulate was located on top of a high-rise dormitory on the University of Montana campus. Suspended particulate was analysized for sulfate, benzene soluble fraction, and lead concentrations. Even at this elevation of 150 feet above the ground, measureable amounts of atmospheric lead were detected.

In the Missoula Valley climatic modification can also be associated with air pollution and human activity. It was found that increased fog, decreased visibility, lower cloud ceiling, increased relative humidity, and an urban heat island may all be associated with increased human activity and air pollution in the valley Also it was discovered that meteorological variables have a definite influence on atmospheric particulate levels. Low windspeed, temperature inversion, zero rainfall, and high barometric pressure are all associated with elevated particulate levels in Missoula.

The final phase of this study dealt with the relationship between air pollution and respiratory disease in the Missoula Valley. Three sources of data for respiratory illness were obtained: 1) physicians visits for respiratory illness, 2) hospital admissions, and 3) respiratory deaths. These data were correlated with various environmental parameters and the time series, age specific and sex specific incidence of various diseases was determined. In general the hospital admission rates for chronic respiratory illnesses have increased in the Missoula area since 1955 while the acute respiratory disease admission rates have remained constant or decreased. Respiratory deaths, particularly pneumonia and emphysema, have increased in the past 20 years. A significant inverse correlation was found between atmospheric temperature and the hospital admission rates for pneumonia, bronchitis, and acute upper respiratory infection. A dramatic positive correlation was also found between reduced visibility due to smoke, fog, or haze and hospital admissions for acute upper respiratory infection.

CLIMATIC MODIFICATION AND AIR POLLUTION METEOROLOGY IN THE MISSOULA VALLEY

University of Montana Student Environmental Research Center

Environmental Monograph # 1

John McBride, Christine Anderson, Bruce Bunger

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TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

Figure		Page
3.14	Annual Average Relative Humidity 1700 M.	55
3.15	Annual Average Relative Humidity 2300 M.	56
3.16	Average Annual Precipitation for Missoula 2WNW, Missoula County Airport and Missoula City Stations.. ..	61
3.17	Number of Days per Year with Precipitation Greater Than .01 Inches..........................	62
3.18	Number of Days per Year with Precipitation Greater Than .10 Inches................	64
3.19	Annual Number of Thunderstorms..........	65
3.20	Pre and Post Pulp Mill Precipitation.....	68
3.21	Difference Between Pre and Post Pulp Mill Means.. ...	69
3.22	Annual Number of Days with Heavy Fog..................	70
3.23	Comparison of Heavy Fog Days....	73
3.24	Double Mass Analysis of Fog Data....	74
3.25	Number of Hours per Year with Visibility 6 Miles or Less at the Missoula County Airport...	75
3.26	Number of Hours per Year with Visibility 3 Miles or Less at the Missoula County Airport....	76
3.27	Inversion Index Versus 6 Mile Visibility..	77
3.28	Inversion Index Versus 3 Mile Visibility..	78
3.29	Average Sky Cover at the Missoula Airport.....	80
3.30	Number of Hours per Year with Cloud Ceiling Less Than 5000 Feet at the Missoula Airport....	81
3.31	Number of Days per Year with Cloud Ceiling Less Than 6000 Feet at the Missoula Airport....	83
3.32	Annual Average Percent of Possible Sunshine......... ...	84
3.33	Annual Average Wind Speed..	86
3.34	Prevailing Wind Direction, 1964 - 1971.................	87

Figure		Page

PREFACE

This monograph is the first in a series on environmental concerns in the Missoula Valley region. Future monograph topics include Air Pollution and Respiratory Disease, Precipitation Pollution, H_2S and SO_2 Levels in the Missoula Region, and the Contribution of Road Dust to Atmospheric Particulate Levels. These studies were carried out under the auspices of the University of Montana Student Environmental Research Center with student funds and a National Science Foundation Student Originated Study Grant. This study was carried out entirely by students and the University of Montana Student Environmental Research Center assumes responsibility for the accuracy of the contents. The principal workers in this study are listed on the cover, those students underlined received National Science Foundation stipend support.

We wish to thank Mr. Roland Samel of the Missoula City - County Health Department for supplying the particulate air pollution data and Mr. Ed Nelson of the U.S. Weather Bureau for the Missoula Air Pollution Summary Worksheets. Much of the work presented in this paper was based on this data.

We are deeply indebted to Carol Johnson for typing this manuscript and to Bill Tomlinson for drafting the figures. Their extra efforts are evident throughout the manuscript.

Chapter 1

INTRODUCTION.

The possibility of climatic modification associated with human activity has been a source of controversy in the Missoula region for a number of years. Several papers have been written in an attempt to prove or disprove this phenomena. Perhaps the first published record of climatic modification associated with human activity and air pollution in the Missoula Valley was contained in the proceedings of the Western Montana Medical Society Air Pollution Seminar held in Missoula December 2-3, 1964.[1] Mr. Ed Nelson, Meteorologist-In-Charge, at the Missoula County Airport discussed meteorological evidence which suggested that Missoula has had an increase in the number of days with fog and an increase in the number of hours with visibility six miles or less. In 1968 G. L. Owens published a study entitled Air Pollution in Missoula.[2] Owens dwelt almost entirely on the economic aspects of air pollution control. However, Owens did cite data on the decrease in visibility in the Missoula Valley. Owens related this decrease in visibility to industrialization and relied on Nelson's previous work in drawing his conclucions.

In August 1966, Richard A. Dightman published an ESSA Western Region Technical Memorandum entitled, A Comparison of Fog Incidence at Missoula Montana with Surrounding Locations.[3] Dightman concluded that the incidence of heavy fog at Missoula has materially increased in comparison to surrounding areas. Dightman also suggested that the increased incidence of heavy fog in Missoula was not due to natural climatic variation. In March 1969 Rudolf Honkala published a paper, Visibility in the Missoula Valley, in which he concluded that visibility had shown a marked improvement during the past five years as compared with the previous five year period.[4] He also concluded that visibility problems are seasonal with winter months presenting the most serious problem and that wind direction was of little consequence during months with poor visibility. Honkala also published a letter to Dan Potts of the Hoerner-Waldorf Corporation in which he challenged some of Dightman's conclusions on the incidence of heavy fog in the Missoula Valley.[5] Honkala was especially critical of Dightman's choice of comparison stations. Honkala concluded that although the incidence of fog in Missoula had increased during the period from 1958 to 1965 it had decreased in the period 1966-1968. In the fall of 1969 Thomas E. Horobik presented a paper on the effects of industrial water vapor on precipitation in the Missoula Valley.[6] Horobik concluded that industrial water vapor and hygroscopic nuclei had caused an increase in winter precipitation. More detailed statistical analysis would probably be necessary to justify Horobik's conclusions.

The University of Montana Student Environmental Research Center has undertaken a detailed climatic study of the Missoula Valley. This study was designed to update previous research and to initiate new research on the possibility of climatic modification associated with particulate air pollution and industrial water vapor. The possible effects of hygroscopic nuclei were especially emphasized. The relation between meteorological conditions and particulate air pollution levels in the Missoula Valley was also studied and the possibility of air pollution forecasting based on meteorological conditions was also explored. This particular study was generally limited to suspended particulate and industrial water vapor. Both particulate and industrial water vapor can have major roles in climatic modification and are significant in the Missoula Valley airshed. The role of gaseous air pollutants is also interesting and will be explored as the data becomes available.

Chapter two of this paper deals with particulate air pollution in general and specifically particulate levels in the Missoula Valley region. Procedures for analysis of particulate samples are also discussed. Chapter three presents a detailed climatological analysis of the Missoula Valley and considers the role of human activities as agents of climatic modification. Chapter four deals specifically with observations of smoke and fog at the Missoula County Airport and the meteorological conditions associated with these observations. Finally chapter five contains a study of the correlation between particulate levels and meteorological conditions and a discussion of the possibility of a pollution prediction model for Missoula, Montana based on meteorological conditions.

Chapter 2

ATMOSPHERIC PARTICULATE MATTER

Generally when one considers the topic of air pollution gaseous substances such as sulfur dioxide, hydrogen sulfide, and photochemical smog are brought to mind. However, probably the most ubiquitous air pollutant is atmospheric particulate matter There appears to be some controversy as to exactly what may be considered atmospheric particulate. According to the Air Quality Criteria Document for Particulate Matter, particulate is considered to be any dispersed matter, solid or liquid, in which individual aggregrates are larger than single molecules but smaller than 500 microns.[7] (One micron is one-millionth of a meter.) Solid and liquid water are not considered to be suspended particulate.

Particulate matter is present to some degree throughout the atmosphere,however highest concentrations are generally found in urban and industrial areas. There are numerous sources of atmospheric particulate matter both natural and artifical. Atmospheric particulate is formed by two general procedures, condensation and comminution. Particles below one micron in size are generally produced by condensation, predominately products of combustion and photochemical smog. Larger particles are generally produced by comminution. In urban locations particles in the size range 1-10 microns are generally characteristic of local industry with products of combustion and soil particles also present. Particles larger than 10 microns are often produced by mechanical processes such as grinding, spraying, and wind erosion. The suspended lifetime of particulate matter varies from a few seconds to several months depending on the size of the particle and the height of injection into the atmosphere.

There are numerous methods used in the collection and analysis of particulate matter. Particles larger than 10 microns have appreciable settling velocities and are generally collected by impaction. A procedure which has been widely used in the past has been collection by impaction in dustfall jars.[8] A dustfall jar is a cylindrical jar which is theoretically expected to collect the equivalent of the settleable dust content of an air column of its own diameter extending to the top of the atmosphere. There are obviously numerous variables which could effect this procedure and at best only relative significance can be placed in the results obtained with dustfall jars. Particles in the size range of .1 to 10 microns are usually measured either with a tape sampler or a high volume particulate sampler. In a tape sampler, successive portions of filter paper, usually paper tape, are positioned between an air intake tube and a vacuum connection. Air is drawn through the filter paper for a certain specified time and then a new section of tape is moved into position.[9] Analysis of particulate collected with tape samplers is usually performed by optical methods.

Perhaps the most widely used method for collecting suspended particulate is the high volume air sampler.[10] The high volume sampler contains a motor and blower similiar to a vacuum cleaner. Air is thus drawn through a filter of large area and low air resistance. The filter paper is weighed and air is drawn through the filter for a specified period of time. The filter is then reweighed. The increase in weight divided by the amount of air drawn through the filter gives particulate concentration in mass per unit volume of air. The air flow through the filter is measured by a flow meter which is calibrated with a calibrated orfice unit. The sampler is enclosed in a shelter which keeps out rain and snow. The shelter also generally prevents collection of particles larger than 100 microns. High volume particulate samplers are in general use throughout the United States. The National Air Surveillance Networks have been collecting high volume particulate data since 1957 and much comparison data is available.[11] The high volume sampling method has been selected by the U. S. Government as the standard method for sampling suspended particulate and Federal Standards for suspended particulate have been promulgated.[10]

Analysis of particulate below .1 micron in size can be performed in several ways. The mass fraction of particles below .1 micron is usually quite small thus particulate concentrations in this size range are normally reported as number per unit volume rather than mass per unit volume. Particle counts can be determined by using cloud chambers, diffusion tunnels, particle mobility in an electric field, or electron microscopy.[12-15] Research in this area is rapidly expanding however much more information is needed on the nature and effects of small particulate. Even an effective standardized monitoring procedure appears to be presently lacking.

High volume particulate data has been collected in most large American cities for a number of years. Figure 2.1 contains some average particulate sampling data for 60 standard metropolitan statistical areas from the National Air Surveillance Network (NASN) for the period 1961-1965.

Standard Metropolitan Statistical Area	Total suspended particles		Benzene-soluble organic particles	
	ug/m3	Rank	ug/m3	Rank
Chattanooga	180	1	14.5	2
Chicago-Gary-Hammond-East Chicago	177	2	9.5	19.2
Philadelphia	170	3	10.7	12.5
St. Louis	168	4	12.8	4
Canton	165	5	12.7	5
Pittsburgh	163	6	10.7	12.5
Indianapolis	158	7	12.6	6
Wilmington	154	8	10.2	15
Louisville	152	9	9.6	18
Youngstown	148	10	10.5	14
Denver	147	11	11.7	8.5
Los Angeles-Long Beach	145.5	12	15.5	1
Detroit	143	13	8.4	28
Baltimore	141	14.5	11.0	10
Birmingham	141	14.5	10.9	11
Kansas City	140	16.5	8.9	23
York	140	16.5	8.1	34
New York-Jersey City-Newark-Passaic-Patterson-Clifton	135	18	10.1	16
Akron	134	20	8.3	30.5
Boston	134	20	11.7	8.5
Cleveland	134	20	8.3	30.5
Cincinnati	133	22.5	8.8	25
Milwaukee	133	22.5	7.4	42
Grand Rapids	131	24	7.2	44.5
Nashville	128	25	11.9	7
Syracuse	127	26	9.3	23
Buffalo	126	27.5	6.0	56
Reading	126	27.5	8.8	25
Dayton	123	29	7.5	40.5
Allentown-Bethlehem-Easton	120.5	30	6.8	50
Columbus	113	31.5	7.5	40.5
Memphis	113	31.5	7.6	39
Portland(Oregon)	108	34	9.5	19.5
Providence	108	34	17.7	38
Lancaster	108	34	6.8	50

Figure 2.1

Suspended Particle Concentrations (Geometric Mean of Center City Station) In Urban Areas, 1961 to 1965. (from Air Quality Criteria For Particulate Matter, January 1969)

Standard Metropolitan Statistical Area (cont.)	Total suspended particles		Benzene-soluble organic particles	
	ug/m3	Rank	ug/m3	Rank
San Jose	105	36.5	14.0	3
Toledo	105	36.5	5.6	58
Hartford	104	38.5	7.1	46
Washington	104	38.5	9.4	21
Rochester	103	40	6.1	55
Utica-Rome	102	41	7.0	47
Houston	101	42	6.8	50
Dallas	99	43	8.8	25
Atlanta	98	44.5	7.8	36.5
Richmond	98	44.5	8.3	30.5
New Haven	97	46	7.3	43
Wichita	96	47	5.2	60
Bridgeport	93	50	7.2	44.5
Flint	93	50	5.3	59
Fort Worth	93	50	7.8	36.5
New Orleans	93	50	9.7	17
Worcester	93	50	8.2	33
Albany-Schenectady-Troy	91.5	53	6.6	52
Minneapolis-St. Paul	90	54	6.5	53
San Diego	89	55	8.5	27
San Francisco-Oakland	80	56	8.0	35
Seattle	77	57	8.3	30.5
Springfield-Holyoke	70	58	7.0	47.5
Greensboro-High Point	60	59	6.3	54
Miami	58	60	5.7	57

Figure 2.1 -- continued

Figure 2.2 shows a distribution of selected cities by population and particulate concentration. Figure 2.3 shows some chemical concentrations from particulate samples in the NASN. This data demonstrates the wide range of particulate concentrations in American cities. Average particulate concentrations range from about 10 ug/M^3 in remote non-urban areas to over 220 ug/M^3 in large urban areas for an annual average. Twenty-four hour concentrations as high as 2000 ug/M^3 have been reported in

Population class	40	40 to 59	60 to 79	80 to 99	100 to 119	120 to 139	140 to 159	160 to 179	180 to 199	200	Total cities in table	Total cities in U.S.A.
3 million	--	--	--	--	--	--	1	--	1	--	2	2
1-3 million	--	--	--	--	--	--	2	1	--	--	3	3
0.7-1 million	--	--	1	--	2	--	4	--	--	--	7	7
400-700,000	--	--	--	4	5	6	1	1	1	--	18	19
100-400,000	--	3	7	30	24	17	12	3	2	1	99	100
50-100,000	--	2	20	28	16	12	6	5	1	3	93	180
25-50,000	--	5	24	12	12	10	2	1	2	3	71	---
10-25,000	--	7	18	19	9	5	2	3	1	--	64	[a]5,453
10,000	1	5	7	15	11	2	1	2	--	--	44	---
Total urban	1	22	77	108	79	52	31	16	8	7	401	----

[a] Incorporated and unincorporated areas with population over 2,500.

Figure 2.2

Distribution of Selected Cities by Population Class and Particle Concentration, 1957 to 1967. Avg. particle concentration ug/m^3 (from Air Quality Criteria For Particulate Matter, January 1969)

Pollutant	Number of stations	Concentrations ug/m^3 Arith. average[a]	Maximum
Suspended particulates....	291	105	1254
Fractions:			
Benzene-soluble organics.....	218	6.8	([b])
Nitrates.	96	2.6	39.7
Sulfates....................	96	10.6	101.2
Ammonium................	56	1.3	75.5
Antimony..........	35	0.001	0.160
Arsenic...	133	0.02	([b])
Beryllium.	100	0.0005	0.010
Bismuth..	35	0.0005	0.064
Cadmium.....................	35	0.002	0.420
Chromium....................	103	0.015	0.330
Cobalt............	35	0.0005	0.060
Copper....	103	0.09	10.00
Iron.......................	104	1.58	22.00

Figure 2.3

Arithmetic Mean and Maximum Urban Particulate Concentrations in the United States, Biweekly Samplings, 1960 to 1965. (from Air Quality Criteria For Particulate Matter, January 1969)

Pollutant	Number of stations	Concentrations ug/m^3 Arith. average[a]	Maximum
Lead........................	104	0.79	8.60
Manganese...........	103	0.10	9.98
Molybdenum..................	35	0.005	0.78
Nickel.............	103	0.034	0.460
Tin.........	85	0.02	0.50
Titanium....	104	0.04	1.10
Vanadium................. ...	99	0.050	2.200
Zinc........................	99	0.67	58.00
Gross beta radioactivity.....	323	(0.8 pCi/m^3)	(12.4 pCi/m^3)

[a] Arithmetic averages are presented to permit comparable expression of averages derived from quarterly composite samples; as such they are not directly comparable to geometric means calculated for previous years' data. The geometric mean for all urban stations during 1964-65 was 90 ug/m^3, for the nonurban stations, 28 ug/m^3.

[b] No individual sample analyses performed.

Figure 2.3 -- continued

heavily polluted urban areas. In the Montana State Air Pollution Implementation Plan a particulate concentration of 30 ug/M^3 was considered background level.[16] The geometric mean for particulate in Glacier National Park during the period 1962-1966 was 13.7 ug/M^3 During 1970 the highest particulate levels in Montana were measured in Libby. Libby had an annual geometric mean of 219 ug/m^3 and a 24 hour maximum of 733 ug/M^3. Figure 2.4 shows the Federal Standards promulgated for suspended particulate. The Federal primary standards define levels of air quality which will protect public health with an adequate margin of safety. Secondary standards are designed to protect the public welfare from any known or anticipated adverse effects of a pollutant. Particulate levels in most American cities greatly exceed the Federal primary standards. The State of Montana has also developed Air Pollution Standards.[17-18] Montana particulate

(1) National primary ambient air quality standard for particulate matter
    (a) 75 micrograms per cubic meter annual geometric mean
    (b) 260 micrograms per cubic meter -- maximum 24 hour concentration not to be exceeded more than once a year
(2) National secondary ambient air quality standards for particulate matter
    (a) 60 micrograms per cubic meter annual geometric mean
    (b) 150 micrograms per cubic meter -- maximum 24 hour concentration not to be exceeded more than once a year

Federal Particulate Standards

(1) Total suspended particulate
    (a) 75 micrograms per cubic meter of air, annual geometric mean
    (b) 200 micrograms per cubic meter of air, not to be exceeded more than one percent of days a year
(2) Settled particulate
    (a) 15 tons per square mile per month, 3 month average in residential area
    (b) 30 tons per square mile per month, 3 month average in heavy industrial areas
(3) Sulfate fraction
    (a) 4 micrograms per cubic meter of air, maximum allowabled annual average
    (b) 12 micrograms per cubic meter of air, not to be exceeded over one percent of the time
(4) Lead fraction
    (a) 5.0 micrograms per cubic meter of air, 30 day average
(5) Beryllium
    (a) 0.01 micrograms per cubic meter of air, 30 day average

Montana State Particulate Standards

Figure 2.4 Federal and Montana State Particulate Standards

standards are quite similar to the Federal Standards and are also given in figure 2.4. The State of Montana has also promulgated standards for certain chemical constituents of particulate matter.

Particulate data has been collected in Missoula for over ten years. The first data was collected for the statewide survey, A Study of Air Pollution in Montana, conducted by the State Department of Health in 1961-1962.[19] Particulate readings were collected at the Federal Building and the Forest Research Laboratory west of Missoula. Sampling started

July 25, 1961 and samples were collected every third day using a high volume sampler. Total suspended particulate levels were determined and the benzene soluble, lead, and arsenic fractions were obtained. Figure 2.5 gives the average monthly values obtained for the above measurements. Figure 2.6 gives summary data for Missoula and six other Montana cities for comparison. This study demonstrated that suspended particulate levels in the Missoula Valley were quite high. The benzene soluble fraction of the particulate was higher in Missoula than in any of the other Montana cities sampled. In fact the benzene soluble fraction reported for Missoula was higher than for any of the cities reported in figure 2.1, which includes most of the large metropolitan areas in the United States. The polycyclic hydrocarbon content of the benzene soluble fraction of the particulate was also determined in this study. The benzo (a) pyrene levels for seven Montana cities and three large metropolitan areas are shown in figure 2.7. The benzo (a) pyrene level in Missoula was highest of the seven Montana cities studied.

Following the State Department of Health report intermittent particulate monitoring was conducted by the Missoula City-County Health Department until the fall of 1969.[20] The sampling location was generally the Missoula County Courthouse. Figure 2.8 gives the annual and quarterly average total suspended particulate levels for the period 1961-1962, 1965-1966, and 1966-1967. The annual average total suspended particulate levels range around 150 micrograms per cubic meter of air The State Ambient Air Standard is 75 ug/M^3 for an annual average. These levels are comparable to those found in major metropolitan areas. Figure 2.9 gives the benzene soluble fraction for the same time periods. While the

Monthly Total Particulate Variation

Conc.*	Month
312	Nov.
214	March
182	Feb.
178	April
169	June
151	Jan.
148	Oct.
145	July
144	Dec.
117	May
108	Sept.
103	Aug.

158 Year's average.
104 All cities average.

*Concentration in micrograms per cubic meter of air.

Monthly Arsenic Fraction Variation

Conc.*	Month
0.02	Jan.
0.02	March
0.02	Nov.
0.01	Feb.
0.01	Dec.
0.01	Sept.
0.00	Oct.
0.00	April
0.00	May
0.00	June
0.00	July
0.00	Aug.

0.01 Year's average.
0.08 All cities average.

*Concentration in micrograms per cubic meter of air.

Monthly Organic Fraction Variation

Conc.*	Month
56.6	Nov.
43.5	Jan.
41.9	Oct.
40.7	Feb.
36.3	Dec.
28.3	March
22.9	April
17.3	June
15.4	July
14.9	May
13.3	Aug.
12.0	Sept.

26.6 Year's average.
13.1 All cities average.

*Concentration in micrograms per cubic meter of air.

Monthly Lead Fraction Variation

Conc.*	Month
1.17	Nov.
0.79	Jan.
0.76	Dec.
0.45	Feb.
0.45	March
0.33	Oct.
0.23	April
0.21	Sept.
0.20	July
0.15	May
0.11	Aug.
0.10	June

0.40 Year's average.
0.39 All cities average.

*Concentration in micrograms per cubic meter of air

Figure 2.5

Missoula Particulate Levels 1961-1962 (from _A Study of Air Pollution in Montana_, State Department of Health, July 1961-July 1962).

Concentration of Specific Pollutants in Micrograms per Cubic Meter of Air

Community	Year	Season	No. of Samples	Tot. Sus. Particulate Min.	Tot. Sus. Particulate Max.	Tot. Sus. Particulate Avg.	Benzene Soluble Fraction Min.	Benzene Soluble Fraction Max.	Benzene Soluble Fraction Avg.	Arsenic Min.	Arsenic Max.	Arsenic Avg.	Lead Min.	Lead Max.	Lead Avg.	Fluorides Min.	Fluorides Max.	Fluorides Avg.
Anaconda	1961-62	Year*	123	10	339	87	1.8	22.7	7.9	0.0	2.50	0.45	0.0	3.20	0.54	0.0	0.87	0.08
		June-Aug	32	51	166	104	2.7	17.4	6.9	0.0	1.87	0.52	0.0	2.10	0.48	0.0	0.28	0.05
		Sept-Nov	30	20	225	73	2.7	20.5	6.8	0.0	1.77	0.46	0.03	3.20	0.46	0.0	0.20	0.10
		Dec-Feb	30	11	181	62	1.8	22.7	10.0	0.0	2.50	0.54	0.17	1.65	0.71	0.0	0.22	0.10
		Mar-May	31	10	339	115	3.4	15.1	8.1	0.0	1.34	0.26	0.08	1.70	0.53	0.0	0.87	0.06
		Sept-Feb	60	11	225	67	1.8	22.7	8.4	0.0	2.50	0.50	0.03	3.20	0.58	0.0	0.20	0.10
Billings	1961-62	Year	118	12	554	99	1.8	51.7	8.0	0.0	0.14	0.004	0.0	3.56	0.36	0.0	0.31	0.08
		June-Aug	32	35	196	96	3.3	14.8	6.9	0.0	0.14	0.005	0.0	1.06	0.29	0.0	0.20	0.05
		Sept-Nov	28	17	235	110	2.6	26.4	9.3	0.0	0.04	0.007	0.11	1.22	0.40	0.0	0.20	0.11
		Dec-Feb	28	12	554	83	1.8	51.7	7.6	0.0	0.01	0.001	0.0	3.50	0.40	0.06	0.31	0.12
		Mar-May	30	21	366	103	3.1	23.7	8.1	0.0	0.03	0.005	0.02	3.56	0.35	0.0	0.19	0.05
		Sept-Feb	56	12	554	96	1.8	51.7	8.3	0.0	0.04	0.004	0.0	3.5	0.40	0.0	0.31	0.11
Butte	1961-62	Year	123	14	437	125	0.7	51.4	12.1	0.0	0.55	0.07	0.00	1.5	0.41	0.00	4.86	0.58
		June-Aug	33	44	168	109	2.2	24.6	7.8	0.0	0.22	0.06	0.00	1.00	0.30	0.00	0.48	0.14
		Sept-Nov	30	25	437	115	0.7	51.4	10.9	0.0	0.55	0.09	0.12	1.12	0.38	0.03	4.07	0.53
		Dec-Feb	30	30	317	121	0.7	39.8	17.6	0.0	0.21	0.06	0.08	1.5	0.66	0.10	4.86	1.09
		Mar-May	30	14	425	151	3.2	27.9	11.9	0.0	0.33	0.06	0.02	1.0	0.31	0.0	2.2	0.56
		Sept-Feb	60	25	437	118	0.7	51.4	14.2	0.0	0.55	0.08	0.08	1.5	0.52	0.03	4.86	0.81
Great Falls	1961-62	Year	117	8	209	58	1.4	39.0	5.6	0.0	0.11	0.01	0.01	1.90	0.41	0.0	0.36	0.04
		June-Aug	30	28	173	69	2.0	9.4	5.1	0.0	0.07	0.01	0.01	0.84	0.28	0.0	0.09	0.02
		Sept-Nov	28	10	209	67	1.4	30.0	5.6	0.0	0.11	0.02	0.01	1.90	0.40	0.0	0.16	0.08
		Dec-Feb	28	8	123	37	8	12.3	4.9	0.0	0.03	0.005	0.12	1.50	0.72	0.0	0.36	0.07
		Mar-May	31	8	151	58	2	39.0	6.6	0.0	0.06	0.008	0.01	1.0	0.26	0.0	0.11	0.01
		Sept-Feb	56	8	209	52	1.4	12.3	5.2	0.0	0.11	0.01	0.01	1.90	0.56	0.0	0.36	0.07
Helena	1961-62	Year	119	13	251	72	0.3	18.7	6.3	0.0	0.16	0.02	0.0	2.50	0.34	0.0	0.61	0.10
		June-Aug	31	24	169	80	2.0	8.6	5.3	0.0	0.02	0.005	0.0	0.78	0.16	0.0	0.14	0.04
		Sept-Nov	27	16	163	54	0.3	10.2	4.8	0.0	0.07	0.02	0.0	0.83	0.28	0.0	0.21	0.12
		Dec-Feb	30	13	141	53	3.0	18.7	7.8	0.0	0.16	0.03	0.09	2.20	0.61	0.0	0.30	0.13
		Mar-May	31	19	251	95	4.4	12.8	7.2	0.0	0.16	0.03	0.0	2.50	0.33	0.0	0.61	0.09
		Sept-Feb	57	13	163	53	0.3	18.7	6.3	0.0	0.16	0.03	0.0	2.20	0.45	0.0	0.30	0.12
Libby	1961-62	Year	111	33	421	128	2.7	95.7	27.4	0.0	0.01	.001	0.0	1.30	0.28	0.0	1.16	0.08
		June-Aug	22	40	334	98	2.7	25.6	10.6	0.0	0.00	0.0	0.0	1.80	0.09	0.0	0.20	0.05
		Sept-Nov	29	33	400	113	7.7	95.7	25.0	0.0	0.01	0.001	0.0	0.83	0.24	0.0	0.24	0.11
		Dec-Feb	30	56	394	126	6.4	87.8	48.6	0.0	0.01	0.004	0.12	1.30	0.54	0.0	0.13	0.08
		Mar-May	30	36	421	164	6.7	50.2	21.8	0.0	0.01	0.002	0.01	0.67	0.20	0.0	1.16	0.07
		Sept-Feb	59	33	400	118	6.4	95.7	36.8	0.0	0.01	0.003	0.0	1.30	0.39	0.0	0.24	0.09
Missoula	1961-62	Year	115	15	666	158	2.8	120.6	26.6	0.0	0.15	0.01	0.0	1.60	0.40	0.0	0.38	0.08
		June-Aug	42	15	252	139	2.8	31.4	15.3	0.0	0.01	0.0	0.0	1.00	0.14	0.0	0.11	0.05
		Sept-Nov	19	58	666	189	6.0	68.2	36.5	0.0	0.07	0.01	0.10	0.36	0.57	0.0	0.33	0.15
		Dec-Feb	28	17	423	159	3.7	120.6	40.2	0.0	0.13	0.01	0.08	1.60	0.67	0.0	0.21	0.10
		Mar-May	26	49	424	170	4.5	60.0	22.0	0.0	0.15	0.007	0.04	1.00	0.28	0.0	0.38	0.06
		Sept-Feb	47	17	666	174	3.7	120.6	38.3	0.0	0.13	.01	0.08	1.60	0.62	0.0	0.33	0.13
New York, N.Y.	1954-57(1)	Year	21**	73	532	182	3.6	56.0	14.4	0.0	0.25	0.05	0.02	8.9	2.1	0.0	1.60	0.57
Chicago, Ill.	1954-57(1)	Year	31**	65	714	200	5.9	39.0	15.1	0.0	0.32	0.03	0.0	12.2	1.8	0.0	3.92	1.23
Cincinnati, O.	1954-57(1)	Year	40**	42	336	136	2.1	50.0	10.4	0.0	0.30	0.02	0.1	14.6	2.0	0.0	2.11	0.35
Portland, Ore.	1954-57(1)	Year	40**	21	334	89	0.8	58.8	9.6	0.0	0.06	0.01	0.1	7.1	2.0	0.07	4.06	0.93
San Francisco	1955-57(1)	Year	40**	20	253	76	1.3	57.2	9.2				0.0	0.3	0.1			
Los Angeles	1954-57(1)	Year	19**	50	594	185	3.0	69.4	23.3	0.0	0.65	0.05	0.0	14.1	3.6			

* All June samples were collected in 1962; some of July samples collected in both years; August-December in 1961; January-May in 1962. For all cities except as noted.

** Or more.

(1) For arsenic, lead & fluorides only - all others for years 1957-61.

Figure 2.6

Summary of Measured Atmospheric Concentrations of Total Suspended Particulate, Benzene Soluble Fractions, Arsenic, Lead, and Fluorides in Montana and Other Cities (from <u>A Study of Air Pollution in Montana</u>, State Department of Health, July 1961 - July 1962).

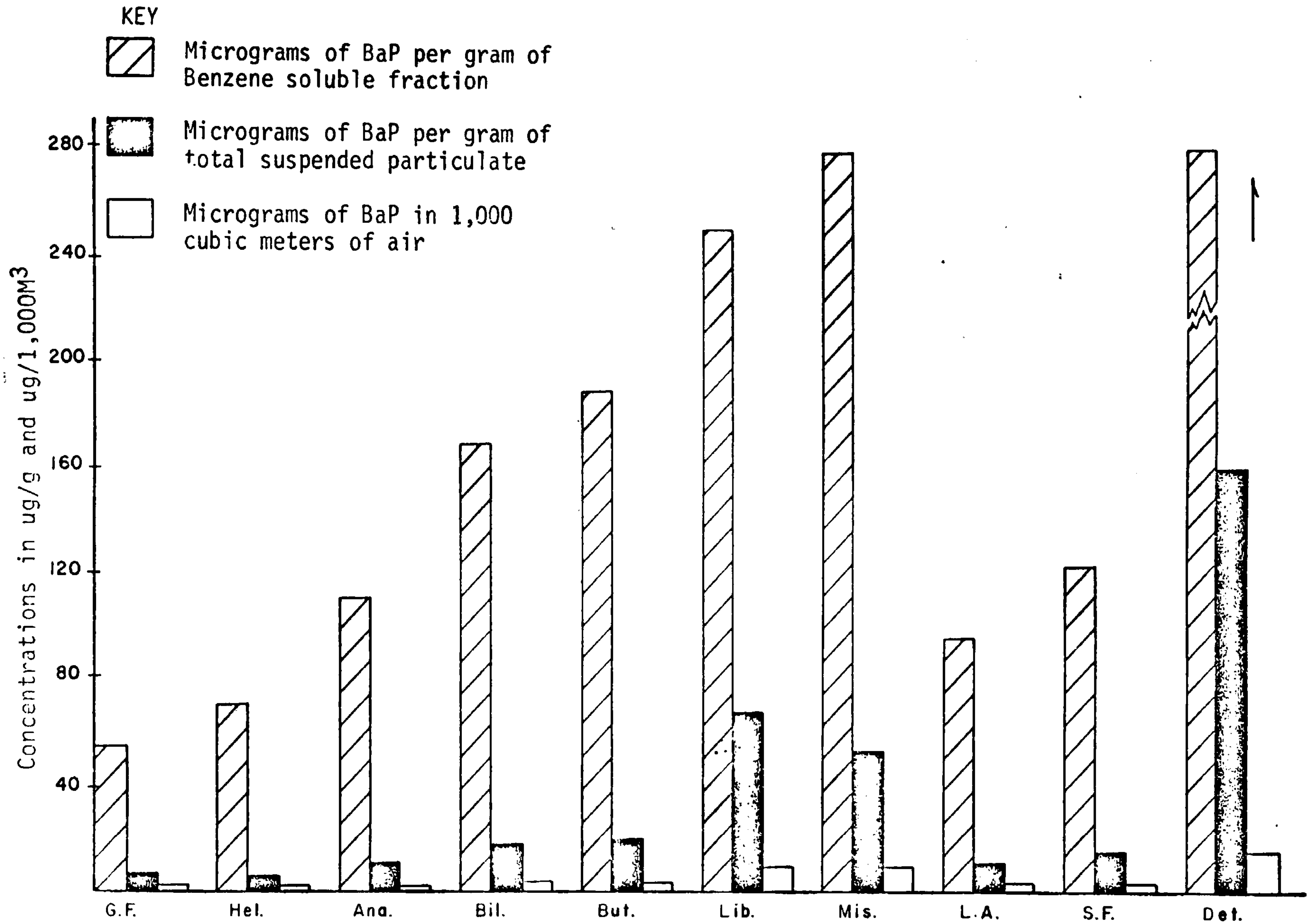

Figure 2.7 Benzo (a) Pyrene (BaP) Content of Air- 7 Montana Cities, July - December 1961 with Comparison Cities (from A Study of Air Pollution In Montana, State Department of Health, July 1961 - July 1962).

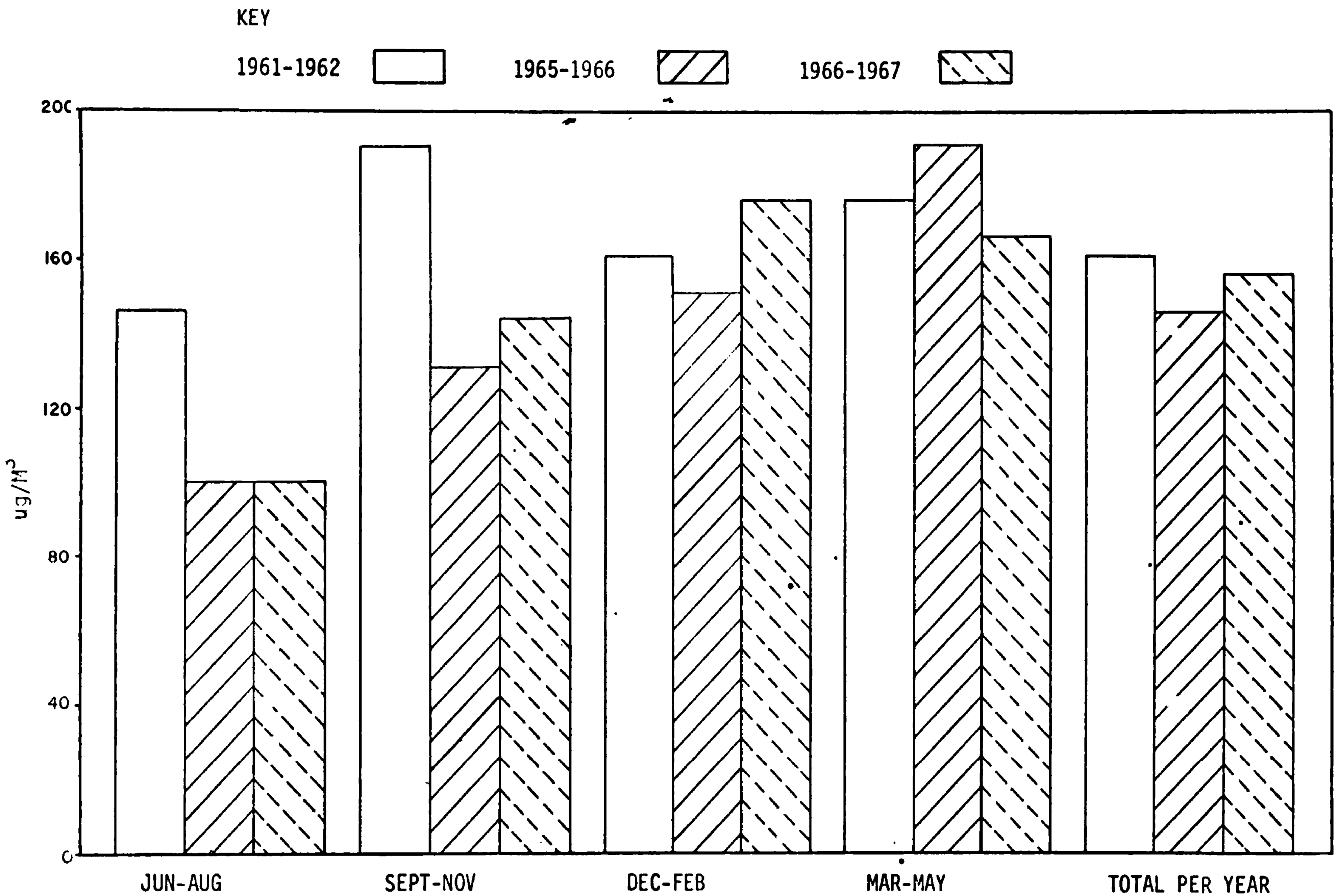

Figure 2.8 Missoula, Total Suspended Particulate (from Original Missoula County Health Department Graphs).

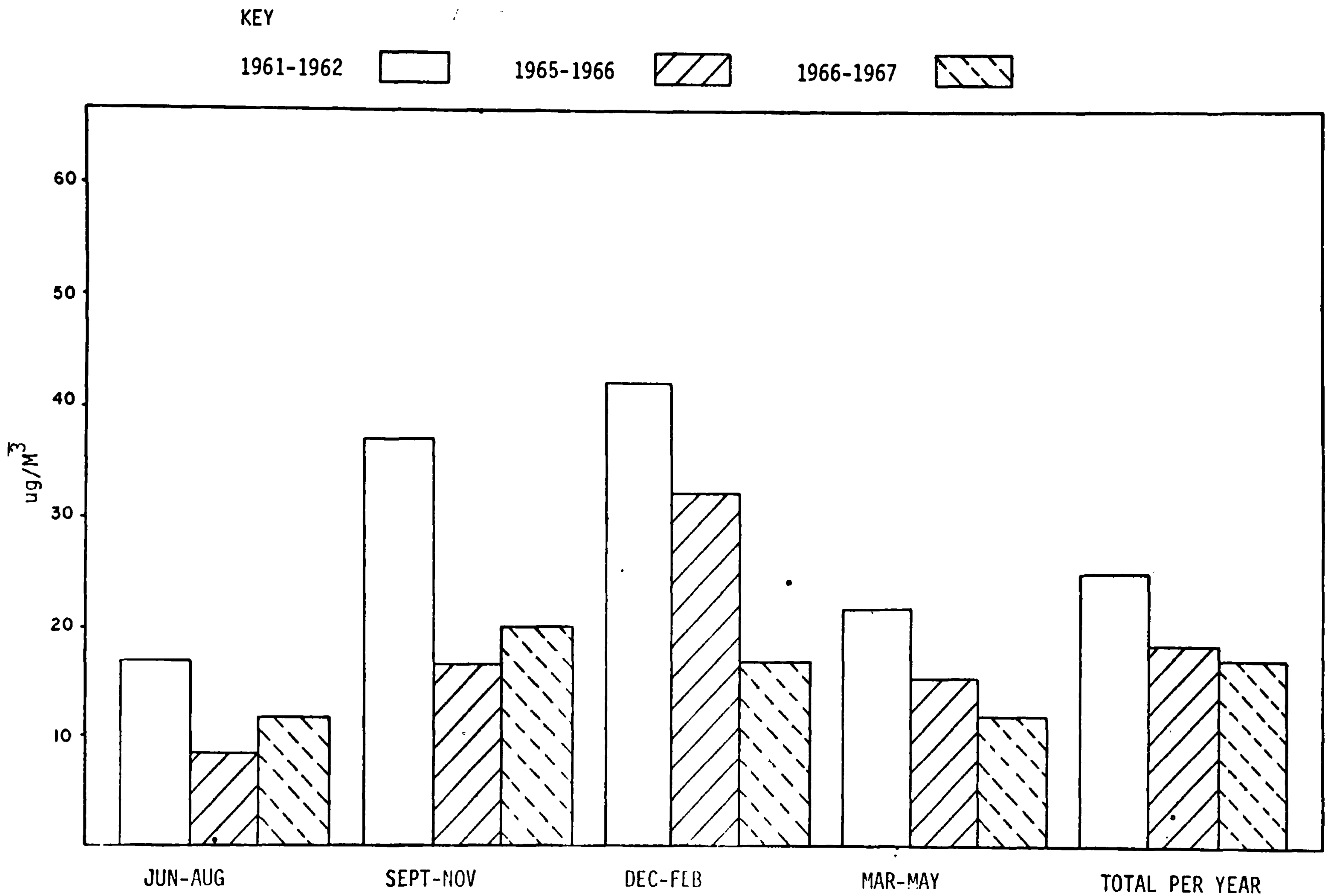

Figure 2.9 Missoula, Organic Fraction of Total Suspended Particulate (from Original Missoula County Health Department Graphs).

benzene soluble fractions levels are not as elevated as the 1961-1962 data, the 1965-1966 and 1966-1967 annual averages are still higher than any of the cities given in figure 2.1. The sulfate fraction of the suspended particulate is given in figures 2.10 and 2.11 for the years 1965-1966 and 1968. The solid line is the state ambient air standard for the sulfate fraction of the suspended particulate.

Particulate sampling was undertaken by the Missoula City-County Health Department on a daily basis begining in September 1969. Presently there are three particulate sampling stations located in the Missoula Valley operated by the City-County Health Department. These samplers are located at the Missoula County Courthouse in downtown Missoula, at the Missoula County Airport, west of Missoula, and at Fort Missoula, southwest of the City. The monthly average total suspended particulate levels at the courthouse sampling site are given in figure 2.12. The benzene soluble and sulfate fractions are shown in figures 2.13 and 2.14. Airport particulate averages are shown in figures 2.15, 2.16 and 2.17, and Fort Missoula particulate data are contained in figures 2.18, 2.19, and 2.20.

Figure 2.12 shows that the total suspended particulate levels recorded at the courthouse have decreased substantially since the daily readings began. The annual average for 1970 was 115 ug/M^3 and 99 ug/M^3 for 1971 as compared to 160 ug/M^3 for 1961-1962. This decrease may reflect the increased control of wood waste disposal in Missoula as the benzene soluble fraction has also decreased significantly. The 1971 annual average was 11 ug/M^3, less than half the level reported in 1961-1962. Particulate from wood waste burners will have a high content of benzene soluble components. Some of the other possible factors affecting the total suspended

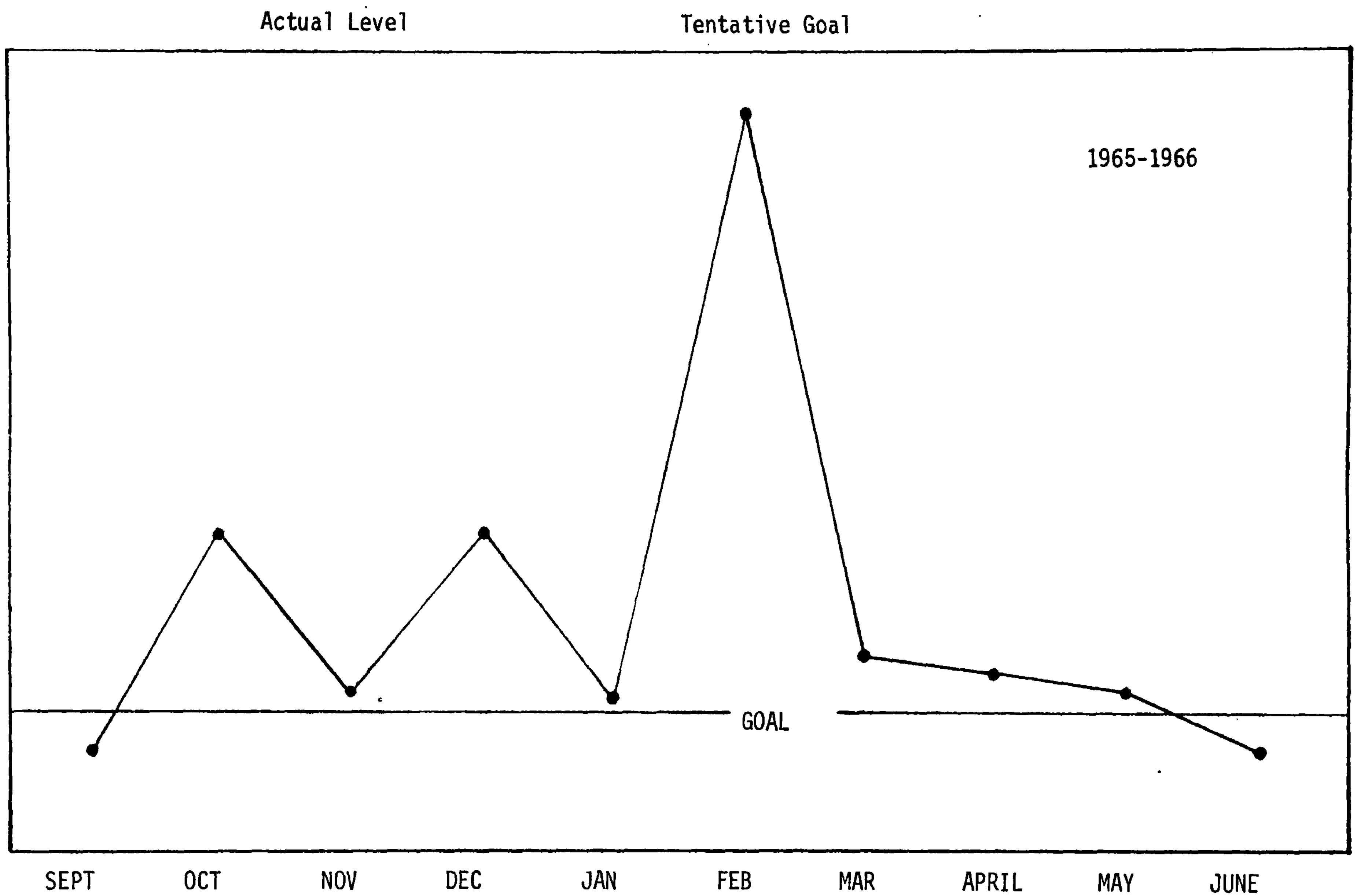

Figure 2.10 Missoula, Sulfate Fraction of Total Suspended Particulate (from Original Missoula County Health Department Graphs)

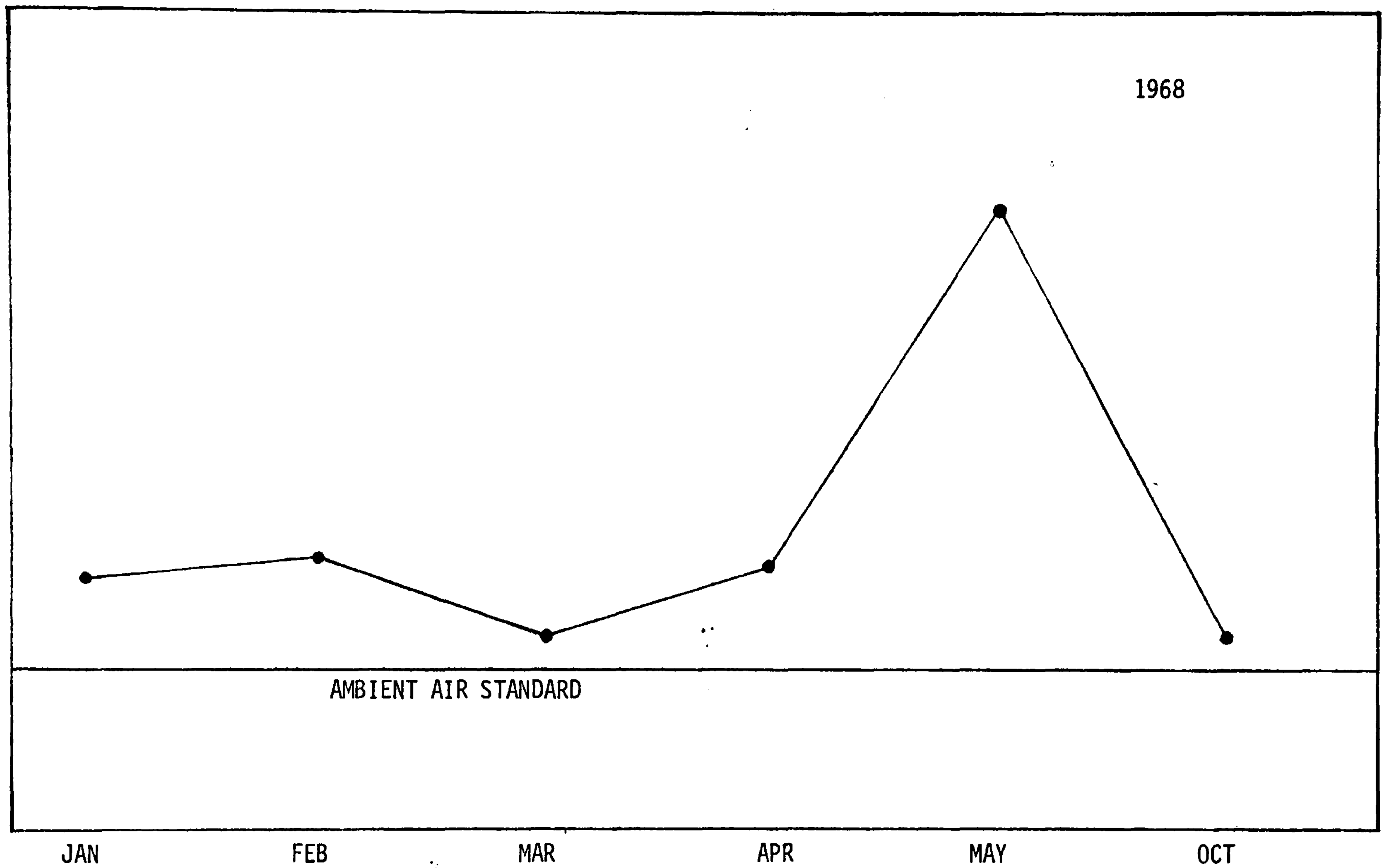

Figure 2.11 Missoula, Sulfate Fraction of Total Suspended Particulate (from Original Missoula County Health Department Graphs).

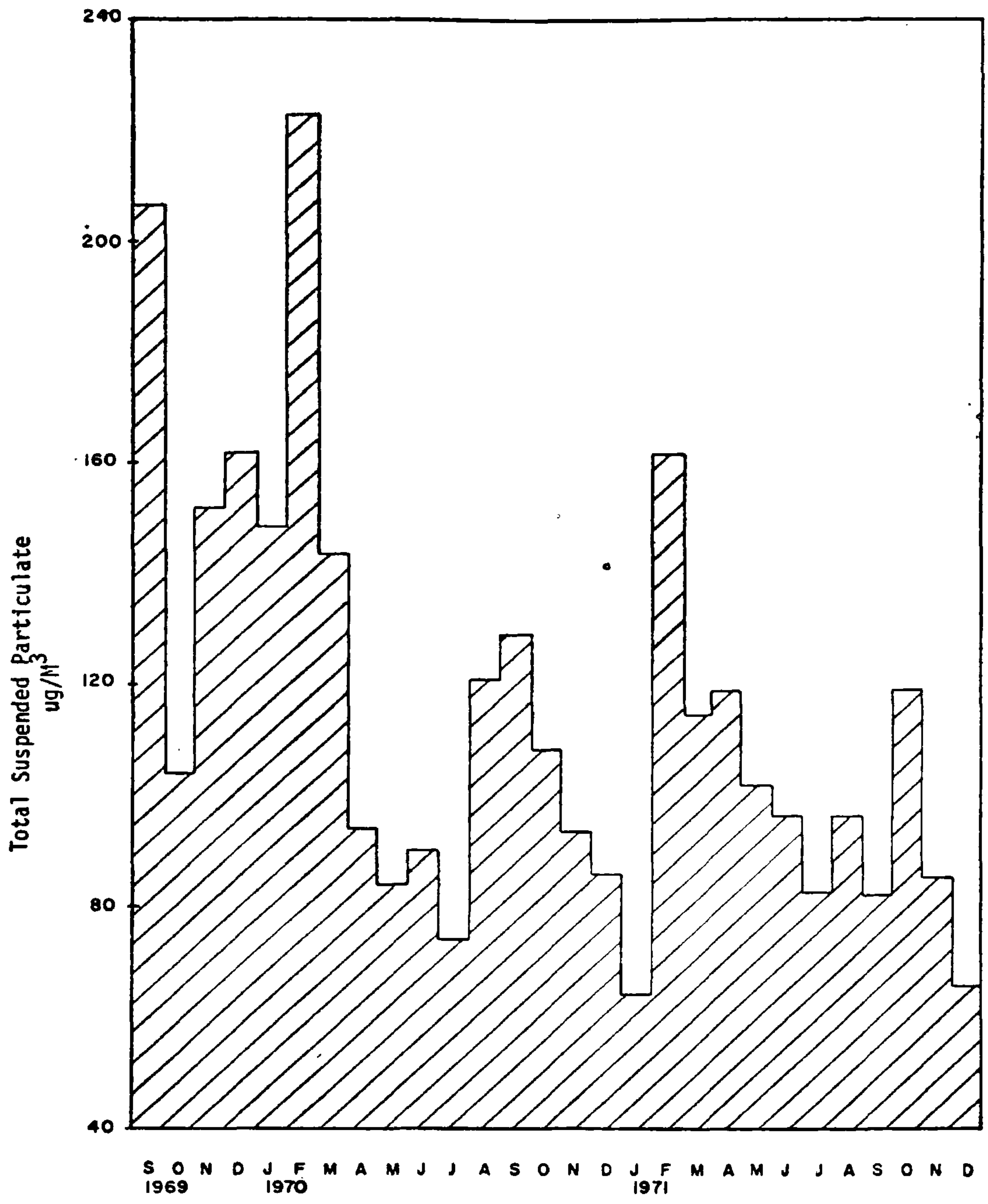

Figure 2.12

Missoula Total Suspended Particulate - Monthly Average Sept. 1969 - Dec. 1971 (from Missoula County Health Department Data) -- Courthouse Sampling Site.

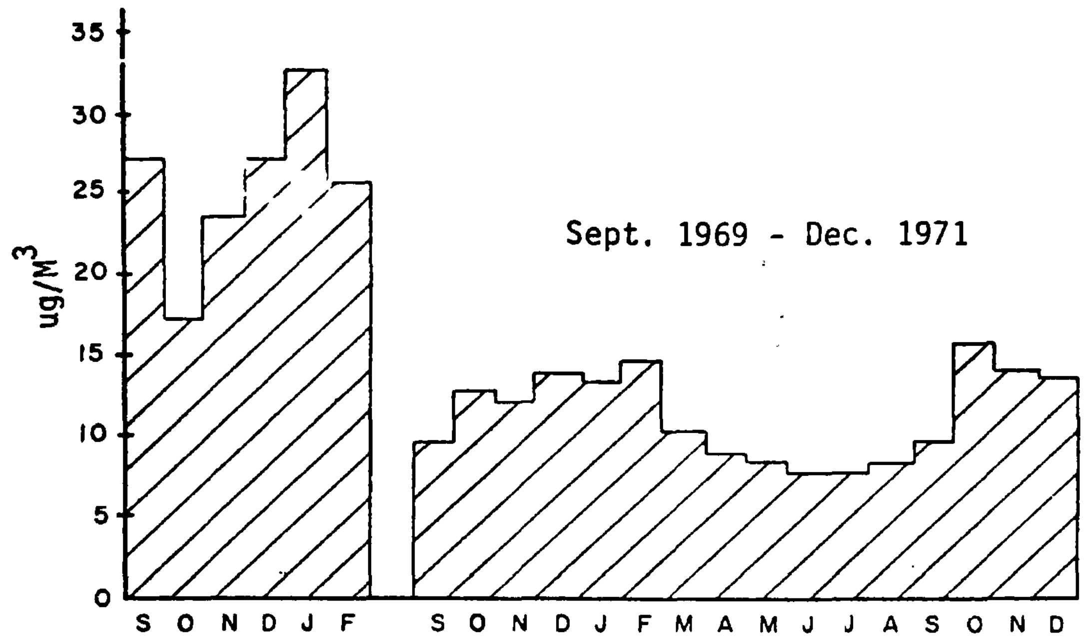

Figure 2.13

Missoula, Benzene Soluble Particulate Fraction (from Missoula County Health Department Data) -- Courthouse Sampling Site.

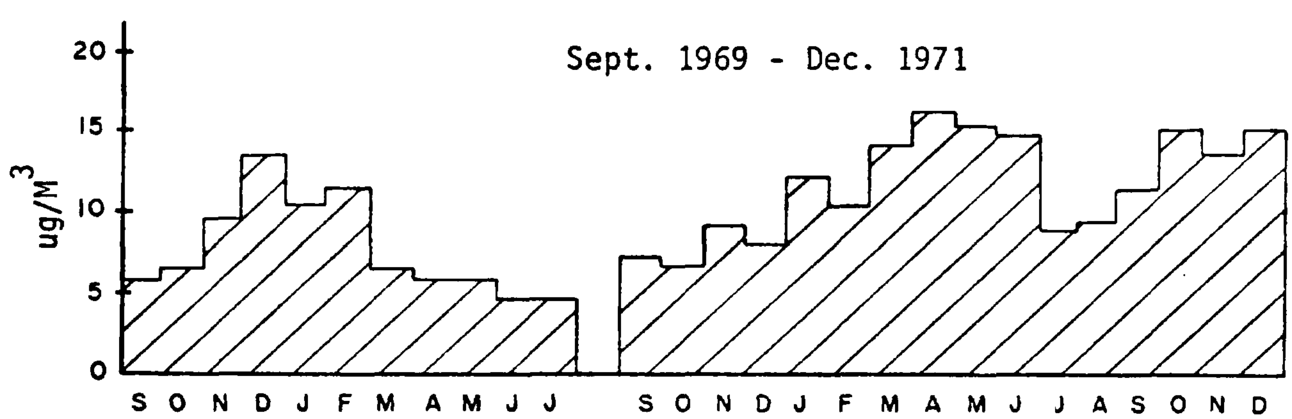

Figure 2.14

Missoula, Soluble Sulfate Particulate Fraction (from Missoula County Health Department Data) -- Courthouse Sampling Site.

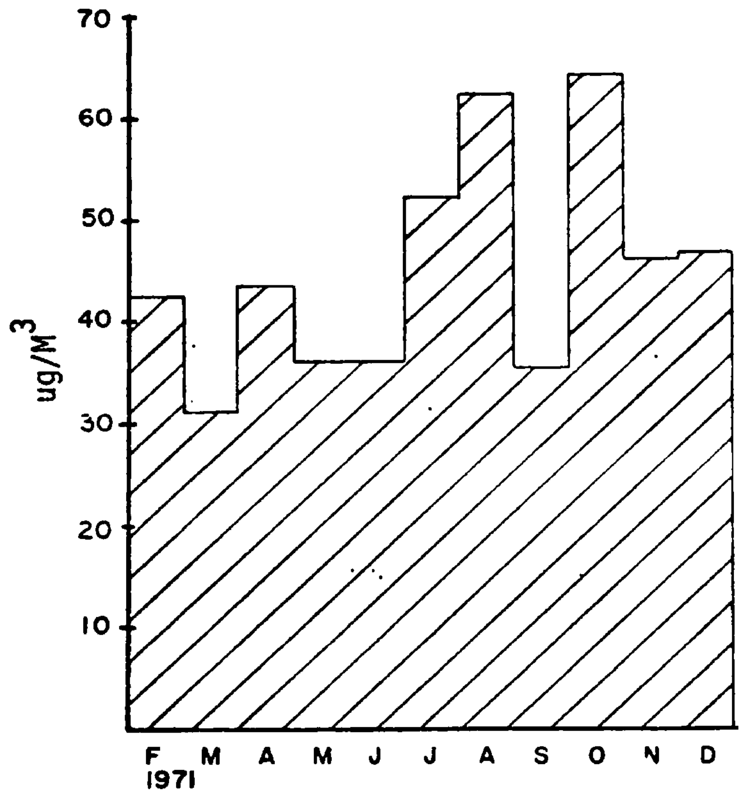

Figure 2.15

Missoula Total Suspended Particulate - Monthly Average Feb. 1971 - Dec. 1971 (from Missoula County Health Department Data) -- Airport Sampling Site.

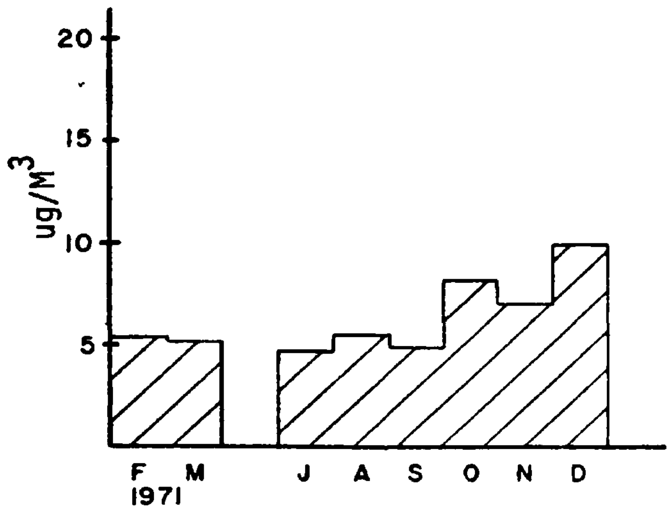

Figure 2.16

Missoula, Benzene Soluble Particulate Fraction (from Missoula County Health Department Data) -- Airport Sampling Site.

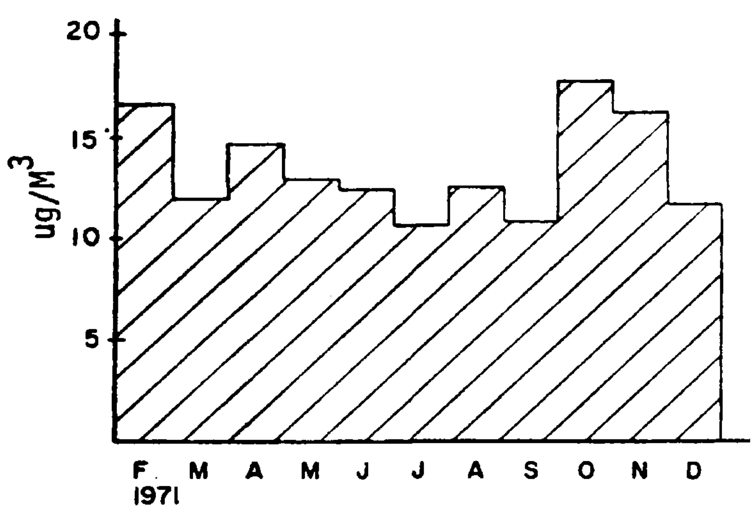

Figure 2.17

Missoula, Soluble Sulfate Particulate Fraction (from Missoula County Health Department Data) -- Airport Sampling Site.

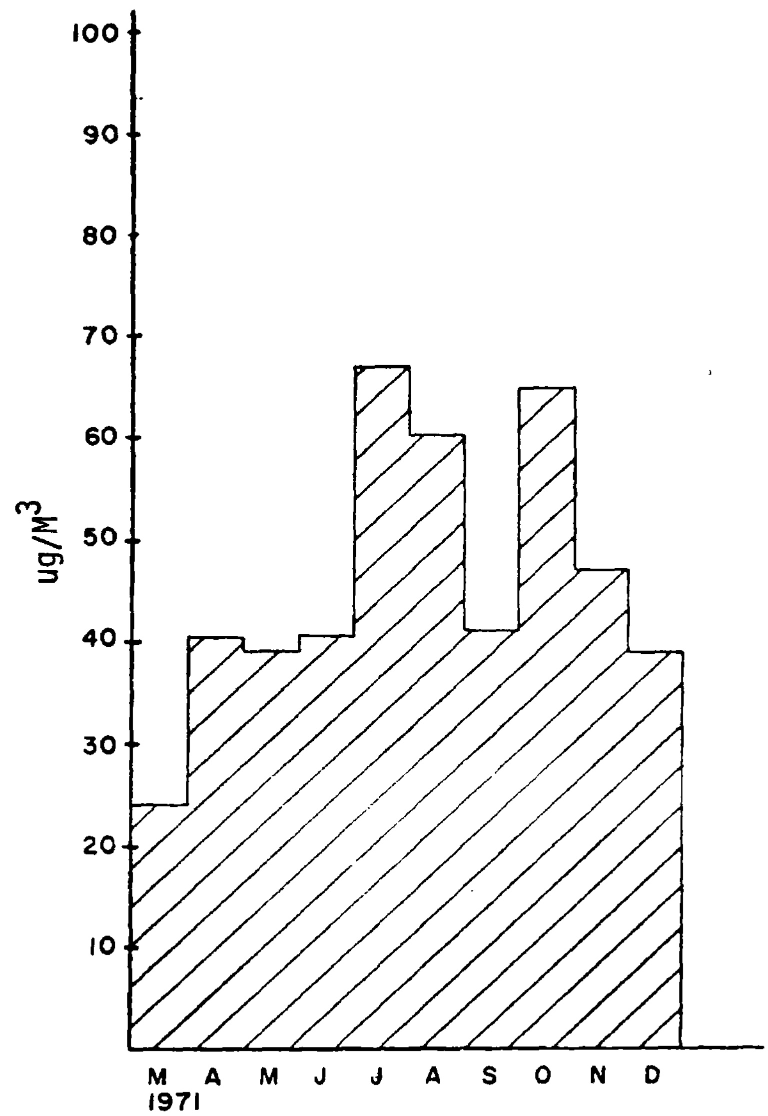

Figure 2.18

Missoula Total Suspended Particulate - Monthly Average Mar. 1971 - Dec. 1971 (from Missoula County Health Department Data) -- Fort Missoula Sampling Site.

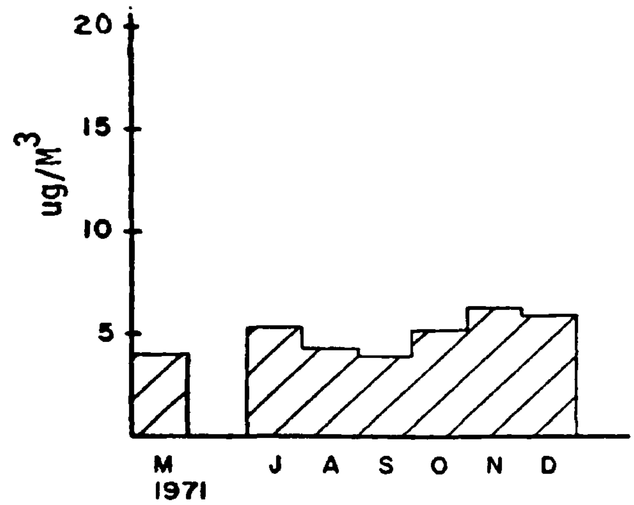

Figure 2.19

Missoula, Benzene Soluble Particulate Fraction (from Missoula County Health Department Data) -- Fort Missoula Sampling Site.

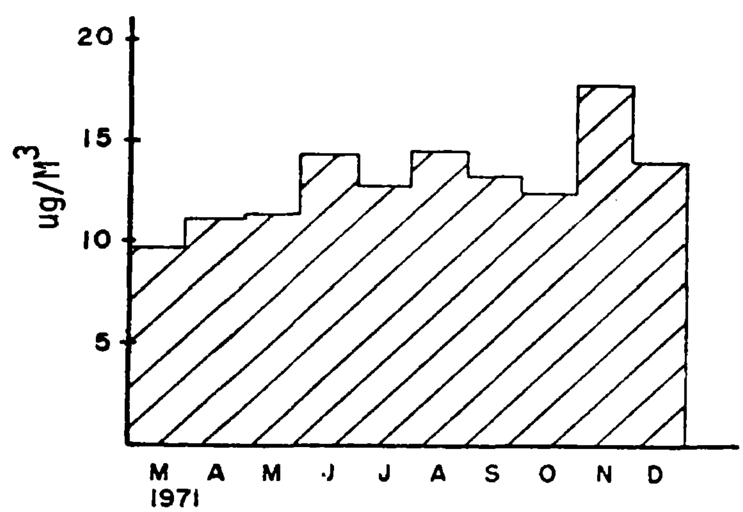

Figure 2.20

Missoula, Soluble Sulfate Particulate Fraction (from Missoula County Health Department Data) -- Fort Missoula Sampling Site.

particulate levels in Missoula will be discussed in subsequent chapters. According the State of Montana air pollution implementation plan a 51% reduction in total suspended particulate from 1970 levels is still needed in Missoula to meet the federal annual geometric mean particulate standard. The Sulfate fraction levels at the Courthouse sampling site have not shown the reduction present in the total suspended particulate and benzene soluble fraction. The soluble sulfate annual average for 1970 was 7.4 ug/M^3. The 1971 average was 13 ug/M^3, over three times the State annual average ambient air standard for soluble sulfate. Sulfate is a common chemical constituent of pulp mill particulate. The particulate levels at the airport and Fort Missoula generally reflect their non-urban location. The particulate levels at the airport and Fort Missoula are ususally less than half the level found at the Courthouse sampling site. The elevated sulfate levels found at the airport sampling location can perhaps be attributed to pulp mill particulate.

In this chapter we have presented a great deal of high volume particulate sampling data. A discussion of the limitations and accuracy of high volume particulate sampling appears necessary. First, it must be understood that a high volume particulate sampler measures only the weight of particulate in a given volume of air. No information concerning the size or number of particles can be determined with this method, although many of the adverse effects associated with particulate air pollution depend on particle size. The chemical composition of particulate collected using the high volume sampling technique can be determined to some degree. Numerous interferences from the filter paper are possible however.

Numerous errors are inherent in the high volume sampling technique, however the precision and accuracy of the method still depends on the analyst. The theoretical repeatibility for a single analyst of the high volume sampling technique is three percent.[21] The reproducibility of the method is 3.7 percent. Careless analytical techniques can greatly increase these values. Some of the errors inherent in the method include a variable flow rate caused by flucuations in line current and inaccurate calibration and averaging of the flow rate. Perhaps the most common error due to the analyst is improper handling of the filters causing weight loss of the collected particulate. The filters are equilibrated at constant humidity for 24 hours before and after use. A delay in weighting can cause a weight loss on the filter due to the loss of volatile organic material. A weight loss of five percent in four days has been reported.[21] The precision and accuracy of the chemical determinations associated with high volume particulate sampling generally depend on the skill of the analyst.

Perhaps the most significant factor affecting the utility of high volume sampling data is sampler location. Usually samplers are located to be representative of the particulate levels in a large area of the community. Atmospheric particulate levels, however, vary widely due to localized sources and care must be exercised to select a representative location. Samplers located next to localized sources such as dusty parking lots, unpaved streets or construction activity can give results which are not representative. The sampling locations in the Missoula Valley appear to be representative of their general area of location. The sampler on the roof of the Courthouse is located close to several busy streets, however, considering the traffic patterns and street locations the values obtained are probably representative of the downtown particulate levels.

The airport sampling location is influenced by airplane and automobile traffic but is probably representative of a large portion of the Western Missoula Valley. The Fort Missoula location is influenced to some degree by automobile traffic however it reflects a generally rural location.

Chapter 3

CLIMATIC MODIFICATION IN MISSOULA

In this chapter we will discuss the role of human activity as an agent of climatic modification. The climate of an area is defined by the long term statistics of various atmospheric variables. Usually the climate of an area is represented by the mean value and variance of a long series of atmospheric observations.[22] Extremes should also be considered in climatic descriptions.[23] In this chapter we will discuss the climate of Missoula with comparison to other localities. We will focus on the trends of various atmospheric variables recorded at the Missoula County Airport and the various factors which could possibly effect these trends. All climatic data presented in this chapter were obtained from published records and worksheets of the United States Department of Commerce, Weather Bureau, located at Johnson Bell Field, the Missoula County Airport.[24]

Missoula, Montana is located in a mountain valley about 60 to 80 miles west of the Continental Divide. The Bitterroot mountains, about 20 miles to the southwest exert a major climatic influence on the valley. The Missoula County Airport mean annual temperature of 43.2°F and annual precipitation of 12.8 inches are indicative of a dry climate. Precipitation is highest in the spring with about 30 percent of the annual total occurring in May and June. Precipitation is quite evenly distributed through the other months with August usually being the driest. Approximately 50 inches of snow is recorded each year. The Continental

Divide shelters Missoula from much of the Continental winter weather. Subzero temperatures can occur anytime from November to March however Missoula averages only ten subzero days per year. The growing season averages 130 days per year with an average of 23 days per year with temperatures greater than 90^{o}F.

The first meteorological variable we will discuss in this chapter is temperature. Temperature is a measure of the degree of hotness or coldness of a body. Temperature is measured with a thermometer which relates changes in hotness or coldness to a change in some physical property of the thermometer.[25] Atmospheric temperature has been recorded since the sixteenth century. Numerous European stations have temperature records 200 to 300 years in length. On a global scale temperature has a major influence on human activities. Temperature is one of the major determining factors in human habitation. The Mean Global temperature and its fluctuation has thus been of interest to scientists for a number of years. J. Murray Mitchell has reported that the world mean temperature increased about 0.7^{o} F during the period from 1880 to 1940. Since 1940 Mitchell reports a drop of about 0.2^{o}F.[26] Numerous theories have been proposed to account for this temperature fluctuation. One of the most intriguing theories proposed to account for the rise in temperature is the "greenhouse effect" In order to understand the "greenhouse effect" we must consider the Earth - Atmosphere system. The atmosphere of the Earth is essentially transparent to incoming visible solar radiation. The Earth absorbs part of this incoming solar radiation which is then reradiated at a different wavelength. The radiation emitted from the Earth is generally in the infrared region of the spectrum. The atmosphere is not transparent to infrared radiation. Dust, water vapor and carbon dioxide absorb infrared radiation. These constituents then reradiate some of this energy back toward the Earth leading to an increase in the Earths energy budget, hence the temperature of the Earth-Atmosphere system is affected by the concentration of carbon dioxide, dust, and water vapor in the atmosphere. While the concentration of water vapor is assumed to have remained essentially constant over time, the atmospheric concentrations of dust and carbon dioxide are known to have increased in the past 100 years. This increase in carbon dioxide concentration, which has been related to an increase in the combustion of fossil fuels, parallels the global increase in temperature. Atmospheric carbon dioxide levels are forecasted to keep increasing, at least until the year 2000. Another factor which has been theorized to be responsible for the global increase in temperature is solar output. An increase in solar output would mean an increase in radiant energy reaching the Earth and hence an increase in temperature. Solar output may perhaps be related to sunspot activity.[27] The increase in sunspot activity since 1880 correlates with the increase in the mean global temperature.

Neither sunspots or the "greenhouse effect" can be used to explain the downturn in the global mean annual temperature since 1940. Reid Bryson suggests that this decrease in temperature may be due to atmospheric particulate matter.[28] The influence of suspended particulate on climate was first recognized in relation to volcanic eruptions.[29] The eruption of Krakatoa in 1883 produced an enormous particulate load which remained airborne up to five years. Summers in the Northern Hemisphere were noticably cooler after the eruption. Some attenuation of the incoming solar radiation was also measured.

The following mechanism has been proposed to account for the role of atmospheric particulate matter in global cooling. Airborne particulate will scatter and absorb both the incoming solar radiation and the energy reradiated from the Earth. If the backscattering of the incoming visible solar radiation is greater than the absorption of reradiated infrared radiation from the Earth by dust, carbon dioxide, and water vapor the mean global temperature could decrease.[30] The ratio of absorption to scattering determines the sign of the change in the planetary albedo. Through the above process the the albedo of the Earth would increase. The Earth's albedo is simply its normal reflectivity. Recently Rasool and Schneider calculated that by increasing the amount of dust in the atmosphere by a factor of four the Earth's albedo could increase from its present value of 31 percent to 33 percent.[32] This increase in albedo could lead to a decrease in the Earth's mean surface temperature of 3.5^{o} Centigrade. M.I. Budyko has calculated that a temperature drop of this magnitude would be sufficient to set off a new ice age.[33] The question now remains: How long would it take for the four fold increase in atmospheric particulate to occur? Some preliminary calculations project that this increase could occur within 50 years. This is an area where continued monitoring and theoretical calculations are clearly necessary. If the above theories are approximately accurate the possibility of large scale climatic modification by particulate air pollution is high.

Both the "greenhouse effect" and particulate cooling theories are based on the assumption that human activities are responsible for the fluctuations in the mean global temperature. The situation is somewhat complicated, however, because climatic fluctuations have obviously occurred naturally. The fact that during more than 90 percent of the geologic past since the Cambrian both polar regions must have been ice free is a startling example of natural climatic fluctuation.[34] During the last glacial maximum, approximately 18,000 to 29,000 years ago, there was a general drop in the mean global temperature of 5^{0} to 6^{0} Centigrade. Figure 3.1 shows climatic conditions over Great Britain at various times in the past.[35] Measureable climatic fluctuations were occurring long before human activities could have had a major influence. The climatic fluctuations of the past 100 years may or may not be natural The task that atmospheric scientists are faced with is sorting possible inadvertent human climatic modification from the background "noise" of natural climatic variation.

While global climatic fluctuations over long periods of time would certainly effect the mean annual temperature in Missoula Valley we are especially interested in short term fluctuations which can possibly be attributed to human activities. One of the most interesting temperature effects which has been attributed to human activities is the urban-rural temperature difference. The center of the city is warmer than the outskirts. This phenomena has been documented for at least 100 years.[36] Studies in Washington D.C. and London have shown that the mean annual minimum temperature of a large city may be as much as 4^{O}F higher than its surroundings with even more pronounced effects possible in the summer and autumn.[37] Daytime differences have also been noted, however, they tend to be obscured by other factors such as topography. The mean annual average temperatures of large cities tend to be about 1^{O}C higher than

Dates (approx.)	Epoch	Mean Temperatures (C°) Summer (July-Aug.)	Winter (Dec.-Feb.)	Annual	Annual Rain-fall (mm)	Annual Evapora-tion (mm)
1901-1950 A.D.	Recent	15.8	4.2	9.4	932	497
1550-1700 A.D.	Little Ice Age	15.3	3.2	8.8	867	467
1150-1300 A.D.	Little Optimum	16.3	4.2	10.2	960	517
900-450 B.C.	Subatlantic	15.1	4.7	9.3	960-979	482

Source: After Lamb, 1966.

Figure 3.1

Average Climatic Conditions over England and Wales (from Inadvertent Climate Modification SMIC, Massachusetts Institute of Technology, 1971)

their surroundings. The city "heat island" effect is pronounced in large cities, however, the effect is by no means linear with city size. "Heat islands" have been noted in Palo Alto, California (population 33,000) and Corvallis, Oregon (population 21,000).[38-39]

Several processes may be involved in the formation of urban "heat islands" During the summer the buildings, concrete, and pavement of urban areas absorb more incoming solar radiation than do the vegetation and soil characteristic of rural locations. Also in urban areas much less of the absorbed energy is used in evaporation since the precipitation run off from streets and buildings is considerable. The man made energy budget of cities is also considerable. During the winter in the midlatitudes the sun angle is low hence the solar input is low and human energy production may equal one third of more of the total solar imput. This excess energy is obviously not present in rural locations. The "blanket" of water vapor, carbon dioxide, and particulate from human activities which generally covers urban areas also absorb energy. The "greenhouse effect" may indeed have a significant effect in localized urban areas.

The rural-urban temperature difference may be evident in the Missoula Valley. The straight line in figure 3.2 shows the mean annual temperatures recorded at the Missoula County Airport since 1943. The Missoula County Airport (Johnson-Bell Field) is located approximately 6.5 miles WNW of the Post Office in downtown Missoula. The instrument elevation at the airport is currently 3190 feet. The dashed line in figure 3.2 represents the mean annual temperatures for the station Missoula 2WNW. This station was located two miles west of the Post Office building downtown, at the American Crystal Sugar Refinery. This station was in existence from 1931 to 1966. The station had an instrument elevation of 3172 feet and is on a general line between the airport and the city center Post Office. While Missoula 2WNW cannot be considered an urban site, it is certainly more influenced by urban conditions than the airport site. The annual differences in temperature between the airport and Missoula 2WNW sites are shown in figure 3.3. We should note that the Missoula 2WNW station has a higher mean annaul temperature than the airport for every year since 1941 as we would expect considering the "heat island" effect. It is interesting to note that figure 3.3 displays a trend of increasing difference in temperature between Missoula 2WNW and the airport station. This trend parallels the population increase in the city of Missoula and probably represents an increasing "heat island" effect. Figure 3.4 shows the average monthly temperatures for Missoula 2WNW and

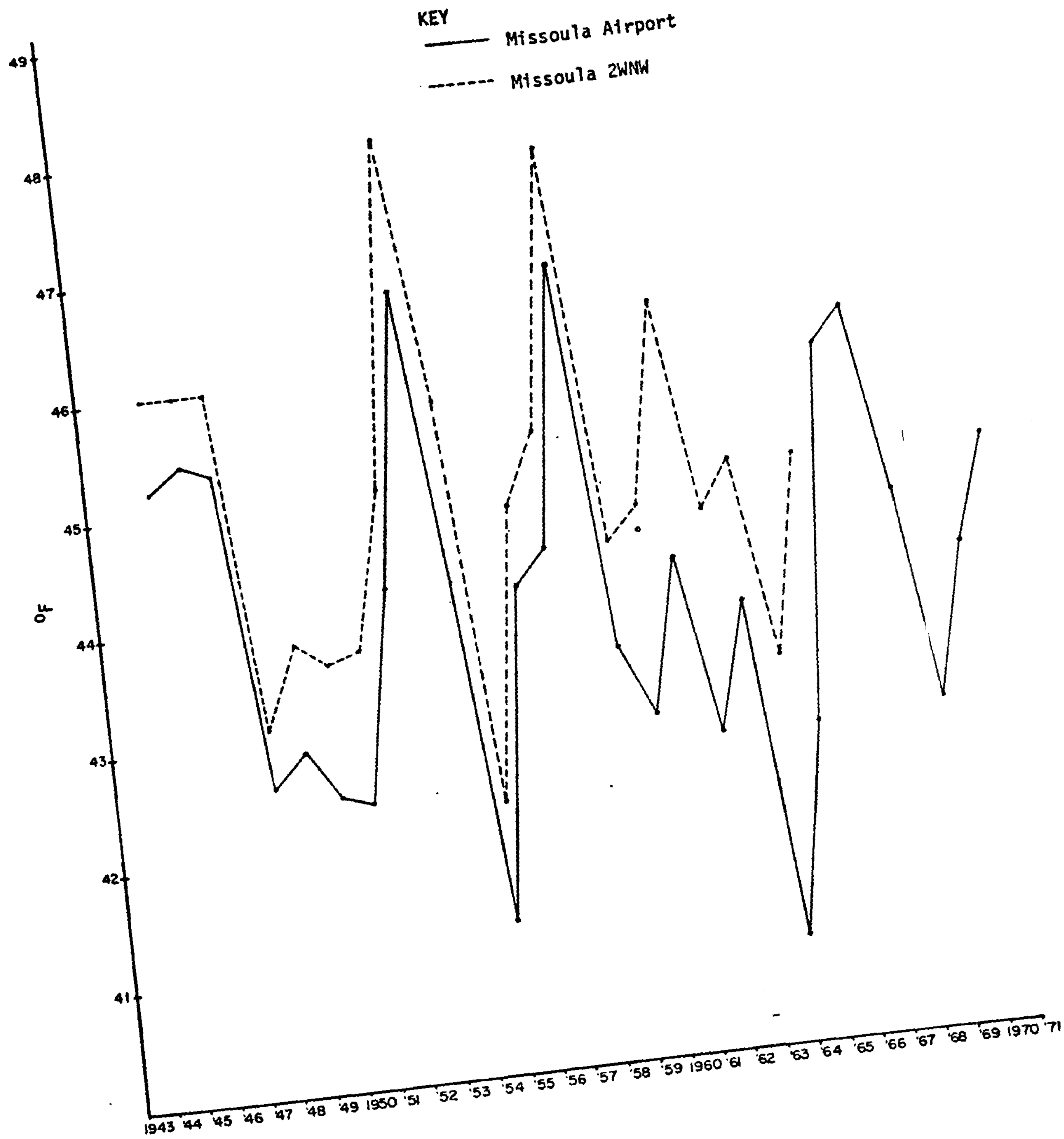

Figure 3.2

Mean Annual Temperature -- Missoula Airport and Missoula 2WNW Stations, 1945-1971.

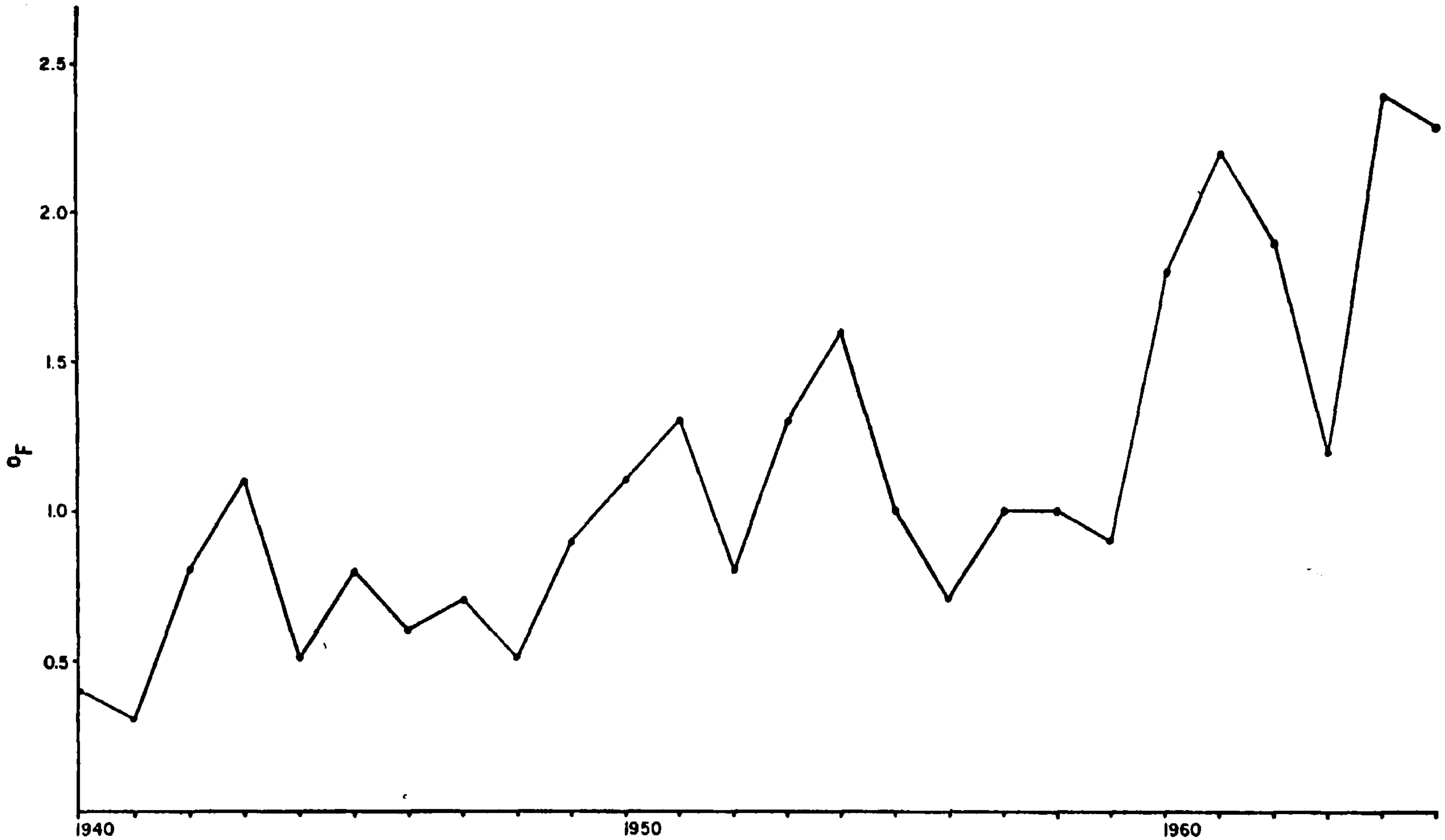

Figure 3.3

Annual Difference in Temperature at Missoula 2WNW and Missoula County Airport Stations, 1940 - 1965.

MISSOULA 2WNW

Month	Mean	Max.	Min.
Jan.	23.5	32.5	14.5
Feb.	28.2	37.6	18.7
Mar.	34.8	45.9	23.5
Apr.	45.6	59.4	31.7
May	54.3	69.0	39.5
June	60.1	75.2	45.0
July	67.7	86.5	48.9
Aug.	65.4	83.9	46.8
Sept.	57.4	74.7	40.1
Oct.	45.6	59.5	31.7
Nov.	32.7	42.5	22.9
Dec.	27.2	35.6	18.8
Annual	45.2	58.5	31.8

MISSOULA COUNTY AIRPORT

Month	Mean	Max.	Min.
Jan.	22.3	30.4	14.1
Feb.	27.1	36.0	18.2
Mar.	33.0	43.2	22.8
Apr.	43.9	56.2	31.4
May	52.6	65.7	39.3
June	58.8	72.5	45.0
July	67.2	84.7	49.7
Aug.	64.6	81.1	48.1
Sept.	56.6	72.0	41.1
Oct.	44.8	57.4	32.2
Nov.	31.6	40.4	22.8
Dec.	26.0	33.5	18.4
Annual	44.0	56.1	31.9

Δ 2WNW - AIRPORT

Month	Mean	Max.	Min.
Jan.	1.2	2.1	0.4
Feb.	1.1	1.6	0.5
Mar.	1.8	2.7	0.7
Apr.	1.7	3.2	0.3
May	1.7	3.3	0.6
June	1.3	2.7	0.0
July	0.5	1.8	-0.8
Aug.	0.8	2.8	-1.3
Sept.	0.8	2.7	-1.0
Oct.	0.8	2.1	-0.5
Nov.	1.1	2.1	0.1
Dec.	1.2	2.1	0.4
Annual	1.2	2.4	-0.1

Figure 3.4

Average Monthly and Annual Mean, Minimum, and Maximum Temperatures -- Missoula Airport and Missoula 2WNW Stations, 1951-1960 the airport stations for the period 1951-1960. The average monthly minimums and maximums for this period is also shown in this figure. One can see from figure 3.4 that the greatest difference in the monthly means between the two stations occurs in the winter. An examination of the average monthly minimums and maximums reveals the cause of this situation. The average annual maximum temperature at Missoula 2WNW is 2.4^{o}F higher than the airport and no seasonal trend is visible in the monthly averages. The average annual minimum temperature at Missoula 2WNW, however, is 0.1^{o}F lower than the airport average and it is distinctly lower in the summer. Literature references generally describe a maximum "heat island" effect noticable in the average minimum temperatures. The situation in Missoula is certainly anomolous and may possibly be explained by topographic factors.

The "heat island" effect is also noticable in weather records from downtown Missoula. A weather station was maintained at the Montana Building at the corner of Higgins and Broadway from 1935 to 1944. During the period from 1940 to 1944 records are available from all three station locations. During this five year period the city center averaged 0.8^{o}F warmer than Missoula 2WNW and 1.5^{o}F warmer than the airport station 6.5 miles WNW of the Post Office.

The vertical temperature profile for Missoula is also of interest. The Missoula Valley has been noted for its frequent temperature inversions. Temperature inversion is a situation where temperature increases with elevation. The evironmental lapse rate, or rate of temperature change with elevation of free air, is important in determining the stability of the atmosphere. An environmental lapse rate of less than 5.5^{o}F decrease per 1000 feet elevation indicates a stable atmosphere where a parcel of air displaced vertically tends to return to its original position. Hence, under conditions of temperature inversion the atmosphere is extremely stable. Under conditions of temperature inversion, contaminants and smoke are trapped by the stable atmosphere and serious air pollution episodes can result. It is interesting to note that because of the "heat island" effect, temperature inversions are generally less strong over the city than the surrounding countryside.[40] However, urban residents are usually not consoled by this fact since pollutors are generally concentrated in the city.

Temperature inversion can occur through several different mechanisms. A common mechanism for temperature inversion is radiative cooling. Radiative cooling occurs on clear, still nights. The radiative heat loss of the surface of the Earth causes conductive cooling of the lower layers of the atmosphere forming a blanket of warm air over the cool air close to the surface. Inversions of this nature are generally local in character and are most rapidly developed over snow surfaces. Mountain valleys such as the Missoula Valley are often subject to inversion since the dense, cold air from hilltops and slopes tends to drain down into the valley as it is formed because of its density. This cold air collects in the valley bottoms creating an inverted lapse rate. Early spring and fall frosts are often found in these valleys because of the inversion conditions. Inversions covering large areas are ususlly associated with frontal systems. When two air masses of different temperature come together the colder air, being more dense, tends to move underneath the warm air and replace it creating an inverted lapse rate. Temperature inversions may also be created by the advection of warm air over a cool surface, or by the general subsidence of a large mass of air. In a subsidence inversion the air is dynamically heated more in the upper portion than at its base.[23] Subsidence inversions are generally associated with large high pressure systems.

Inversion conditions in the Missoula Valley are recorded by the United States Weather Bureau at Johnson-Bell Field. The number of days per month with an inversion recorded sometime during the day are shown in figure 3.5 for the period 1961-1971. This information is obtained from unofficial Weather Bureau worksheets, an example of which is shown in figure 3.6. The inversion duration information is reported from visual observations. As can be seen from figure 3.6 five inversion duration criteria are used to record the inversion duration information. An inversion index may be calcualted from this data. The inversion duration information is given the following numerical rating:

0 = 0	A = 2	E = 4
N = 1	P = 3	

The second day of two consecutive E's is given a value of eight, the third day of three consecutive E's has a value of twelve, and the fourth day of four consecutive E's has a value of sixteen. Hence each day has an inversion index rating from which monthly and annual averages may be determined. Figure 3.7 shows the monthly inversion index for the period 1965 to 1971. Figure 3.8 shows the annual inversion index for the same time period. The weather bureau worksheets also contain the 1200 PM temperatures at the airport and TV Mountain along with the difference between the two stations at 1200 PM.

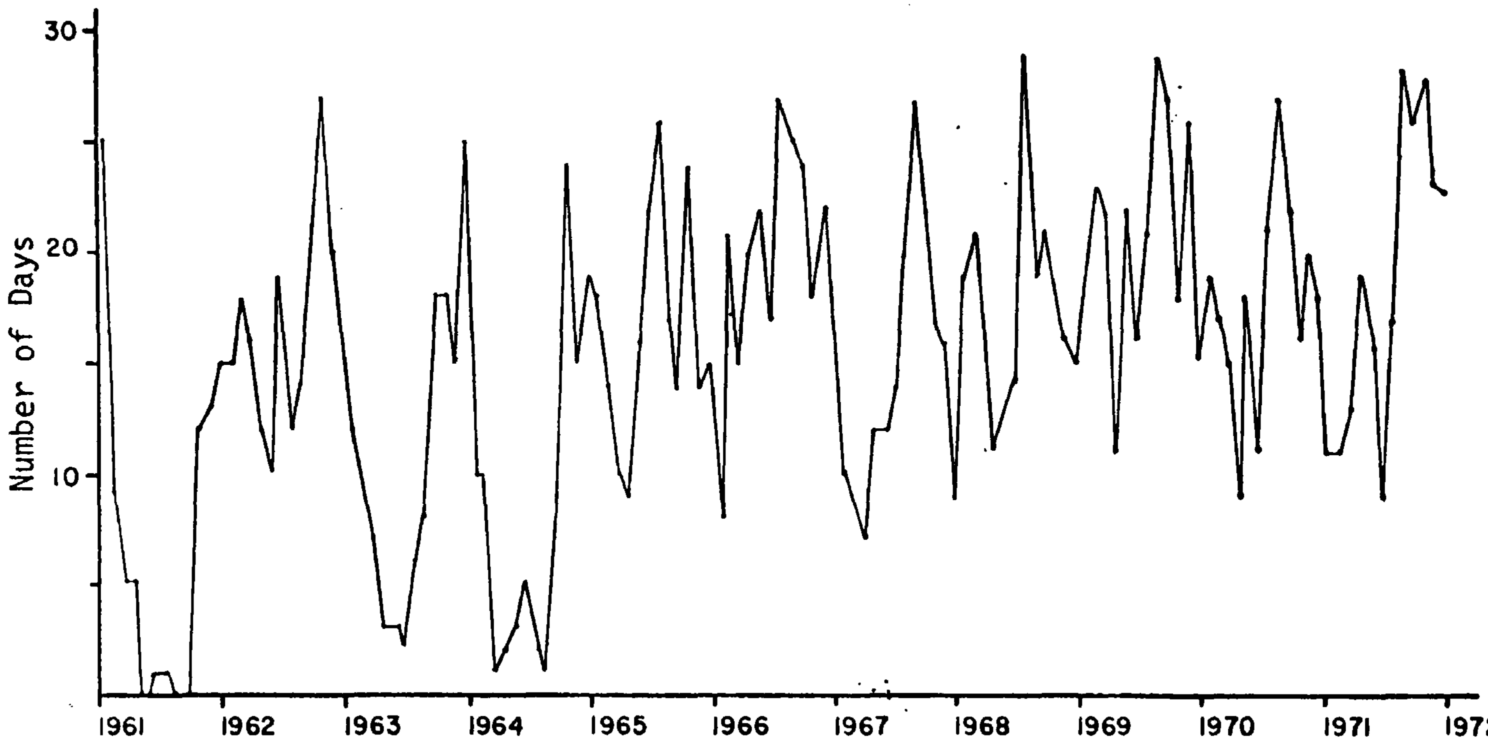

Figure 3.5

Number of Days per Month with Inversion at the Missoula County Airport, 1961 - 1971.

WB FORM 920.1

U. S. DEPARTMENT OF COMMERCE. WEATHER BUREAU
COMPUTATION AND TABULATION SHEET

MISSOULA AIR POLLUTION SUMMARY

JANUARY 1967

Computed by Date Checked by Date Sheet of

Day	MAX* / MIN	Pvlg Wind Drctn	Avg Wind Speed	0900 Vsby & Rstrn	1300 Vsby & Rstrn	1800 Vsby & Rstrn	Min Vsby 06–18 & Rstrn	Time of Min Vsby	Min Vsby 06–18 w.o. Pcpn	Time of Min Vsby w.o.p	24-Hr PCPN	NOON WBAS TEMP	Noon TV-Mtn Temp	Diff. WB-TV	# Invsn Dur. Info.
1	41/20	320	9.8	3 S[illegible]	20	20	3 SW-	[illegible]	4 K	[illegible]	.02	37	24	+13	A
2	35/22	310	6.4	40	20	20	15	0700	15	0700	0	[illegible]	16	+16	0
3	43/27	[illegible]	7.3	15	40	15	6 S-	0700	15	0900	T	41	22	+19	0
4	37/30	130	8.0	3 S-	8 S--	15 R--	2½ S-	0823	15	1500	.02	32	26	6	0
5	39/23	330	10.2	20	15 SW--	15+	15	1400	15	1400	.03	29	12	17	0
6	26/17	320	9.6	10 S--	12	15+	2 S-	[illegible]	10	1000	.02	25	9	16	0
7	30/19	110	4.1	10 S--	7	15	7	1300	7	1300	T	24	12	12	0
8	41/27	320	8.0	20	25	15+	15	0800	15	0800	T	38	24	14	0
9	41/32	260	2.4	15	15	15	10	0800	10	0800	T	36	30	6	0
10	33/28	330	[illegible]	1¼ GFK	½ FK	5/8 FK	¼ FK	1213	¼ FK	1213	0	22	34	2	E
11	44/29	310	5.6	15+	20	15+	15	1600	15	1600	T	42	27	15	N
12	39/33	190	5.1	20	20	15+	15	1600	15	1600	T	38	22	16	0
13	41/32	360	8.2	15	15	8	2 SW-	1701	8	1800	.05	40	24	16	0
14	36/29	150	1.7	2½ GF	4 GFK	6 RW GFK	¾ S GFK	0656	2 GFK	1455	.06	33	25	8	0 ?
15	47/32	310	10.9	25 R--	15 R--	15+ SW-	4 RW-	1627	4 GFK	0656	.13	43	32	11	0
16	39/29	310	9.0	25	40	15+	15+	1800	15+	1800	T	36	17	19	0
17	53/28	300	6.5	20	15 SW--	15	15	1800	15	1800	T	33	16	17	0
18	36/28	300	5.7	40	40	15+	15+	1800	15+	1800	T	33	17	16	0
19	43/34	170	9.9	10 R-	10 R-	10 R-	6 R-	1100	RAIN ENTIRE PERIOD	—	.13	38	28	10	0
20	42/32	160	5.9	4 R-S-	10 RW-	10	15-	0931	7	0956	.16	36	23	13	0
21	34/20	150	4.0	25--GF	2 GF	4 R--F	¼ F	0615	¼ F	0612	.12	34	29	5	0
22	35/17	260	9.7	15	40	40	1 S-	0703	15	0900	.04	32	17	15	0
23	23/10	120	5.4	20	15	10	10	1800	10	1800	0	20	19	1	A
24	21/7	110	6.6	8	4 K	15	4 K	1300	4 K	1300	0	15	17	-2	P
25	23/10	270	1.9	2 S-	7 S--	7 S--	15-	0829	5 K	1500	.04	21	20	1	P
26	[illegible]	300	3.1	8	6 K	15-K	[illegible]	1800	6 K	1300	.04	25	20	5	E
27	36/27	290	3.3	6 ZR-K	3 R-K	5 K	¾ R-K	1356	3 K	0600	.09	32	30	2	E
28	38/31	310	3.8	1½ R= GF	¾ R- GF	¼ GF	0 F	1655	0 F	1655	.11	35	33	2	E
29	41/31	120	4.7	⅛ GF	3 R- GF	15	1/16 R-F	0755	[illegible]	0856	.16	34	33	1	P
30	43/27	340	6.5	60	60	30	15+	0700	15+	0700	T	39	22	17	0
31	37/26	170	3.3	10	7	15	7	1300	7	1500	0	29	24	5	0

* ~~"Daytime maximum": Occurring between 1100M & 2300M only (today).~~
"Overnight minimum": Occurring between 1700M previous day & 1100M today.

#INVERSION DURATION INFORMATION: Base of inversion estd. 2000' or lower (5000' MSL)

0 – None
~~N – Nighttime inversion, broken by 0900M.~~
A – All night & morning inversion, broken by 1300M.
P – All night, morning & afternoon inversion, broken by 1800M.
~~E – evening inversion continuing all day & after 1800M.~~

NOTE: Inversion forming in evening & broken during night classed as "N" next day.

For entry of lowest vsby between 07 & 18M incases where same value reported for several ~~hours, use the time the minimum visibility was last reported.~~

Commerce-Weather Bureau, Washington, D. C.

Figure 3.6

Example of Missoula Air Pollution Summary Sheet (from U.S. Weather Bureau, Missoula County Airport)

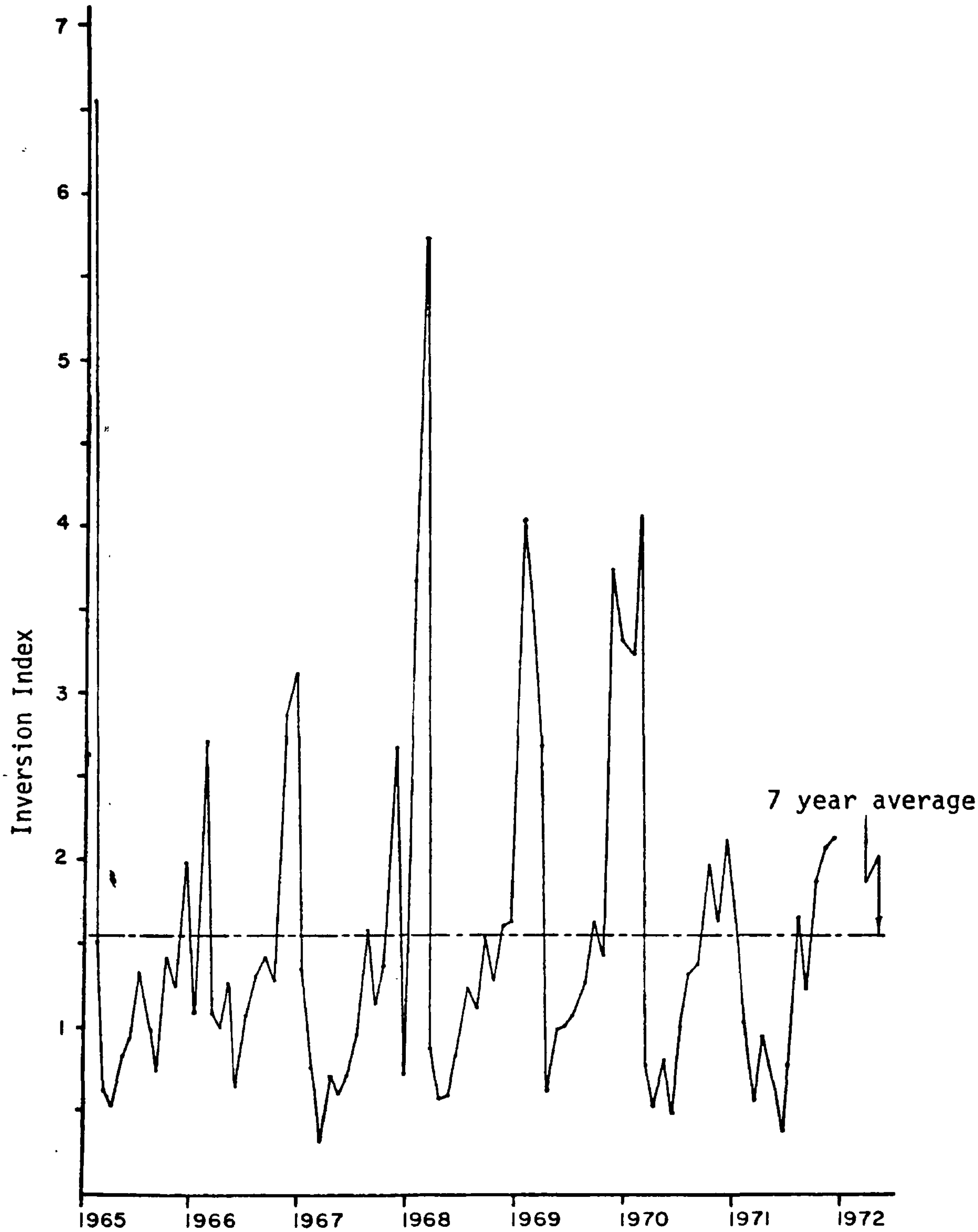

Figure 3.7

Monthly Inversion Index at the Missoula County Airport, Jan. 1965 - Dec. 1971.

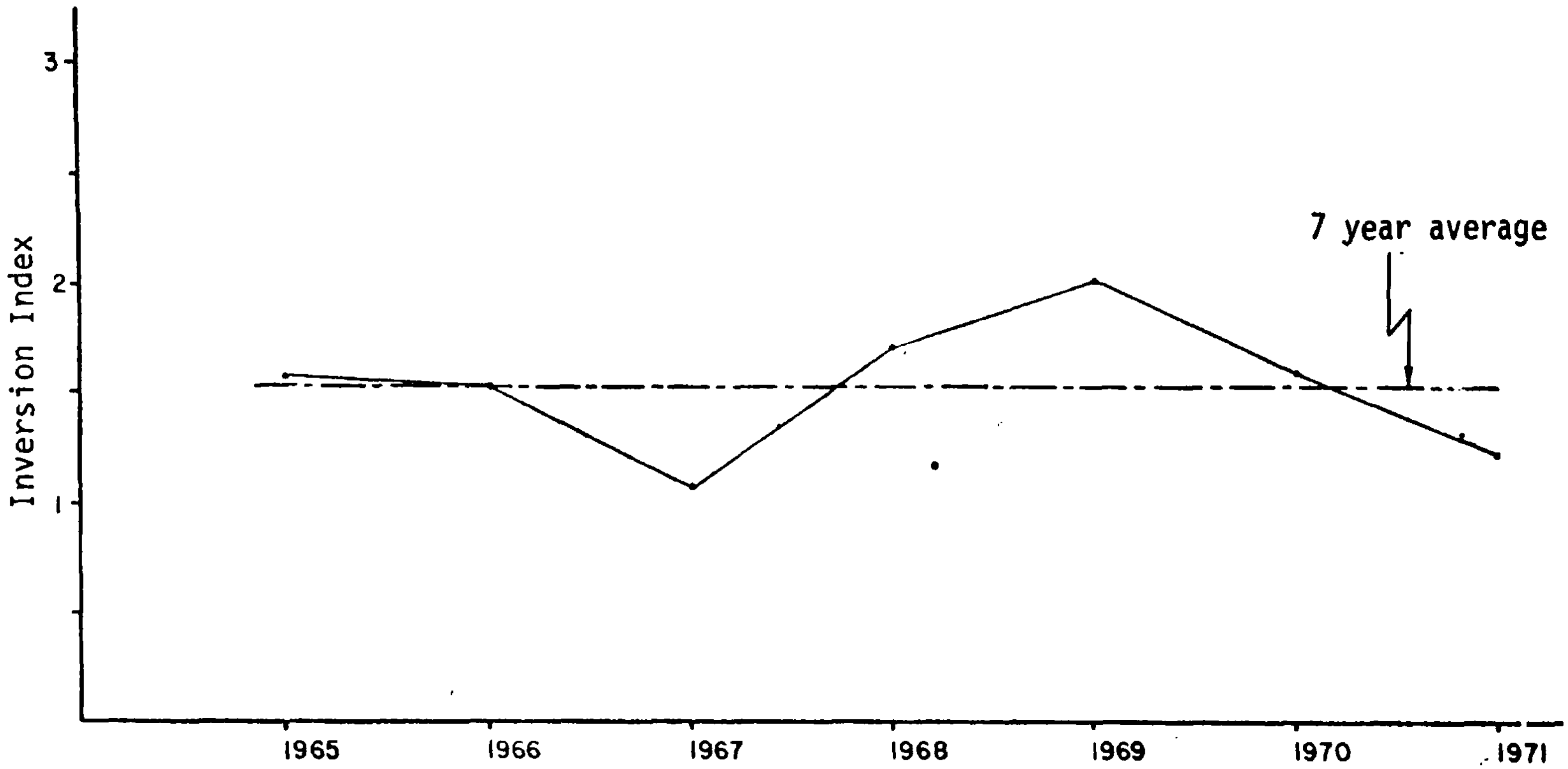

Figure 3.8

Annual Inversion Index at the Missoula County Airport, 1965 - 1971.

The TV Mountain station is approximately eight miles northeast of the airport at an elevation of 6817 feet. The difference in temperature between the airport and TV Mountain gives an indication of the strength of inversion present in the valley at 1200 PM. The average rate of temperature decrease with elevation at 45^{o} N latitude is $3.5^{o}F$ per 1000 feet of elevation hence the average difference in temperature between TV Mountain and the airport should be $12.6^{o}F$.[41] A temperature difference of less than $12.6^{o}F$ indicates inversion conditions. Figure 3.9 shows a plot of the average monthly difference in temperature between TV Mountain and the airport versus the average monthly inversion index for the period September 1969 to December 1971. The relation between the inversion index and the difference in temperature appear to be nearly linear Hence the inversion index seems to be a useful measure of the actual inversion conditions present in the Missoula Valley.

Several meteorological factors effect the formation of temperature inversions. Perhaps the most significant variable is wind speed. Atmospheric turbulence is probably the major factor controlling the formation and persistence of atmospheric temperature inversions. Wind distributes the air masses under inversion conditions and thus distributes the cooling effect through a larger vertical distribution. Figure 3.10 is a plot of the average monthly wind speed recorded at the Missoula County Airport versus the monthly average inversion index for the period September 1969 to December 1971. A strong correlation is obviously present between wind speed and the monthly average inversion index. Figure 3.11 shows the percentage frequency of wind observations below seven miles an hour for various locations in Montana.[42] The 7 mph wind speed is somewhat arbitrary,

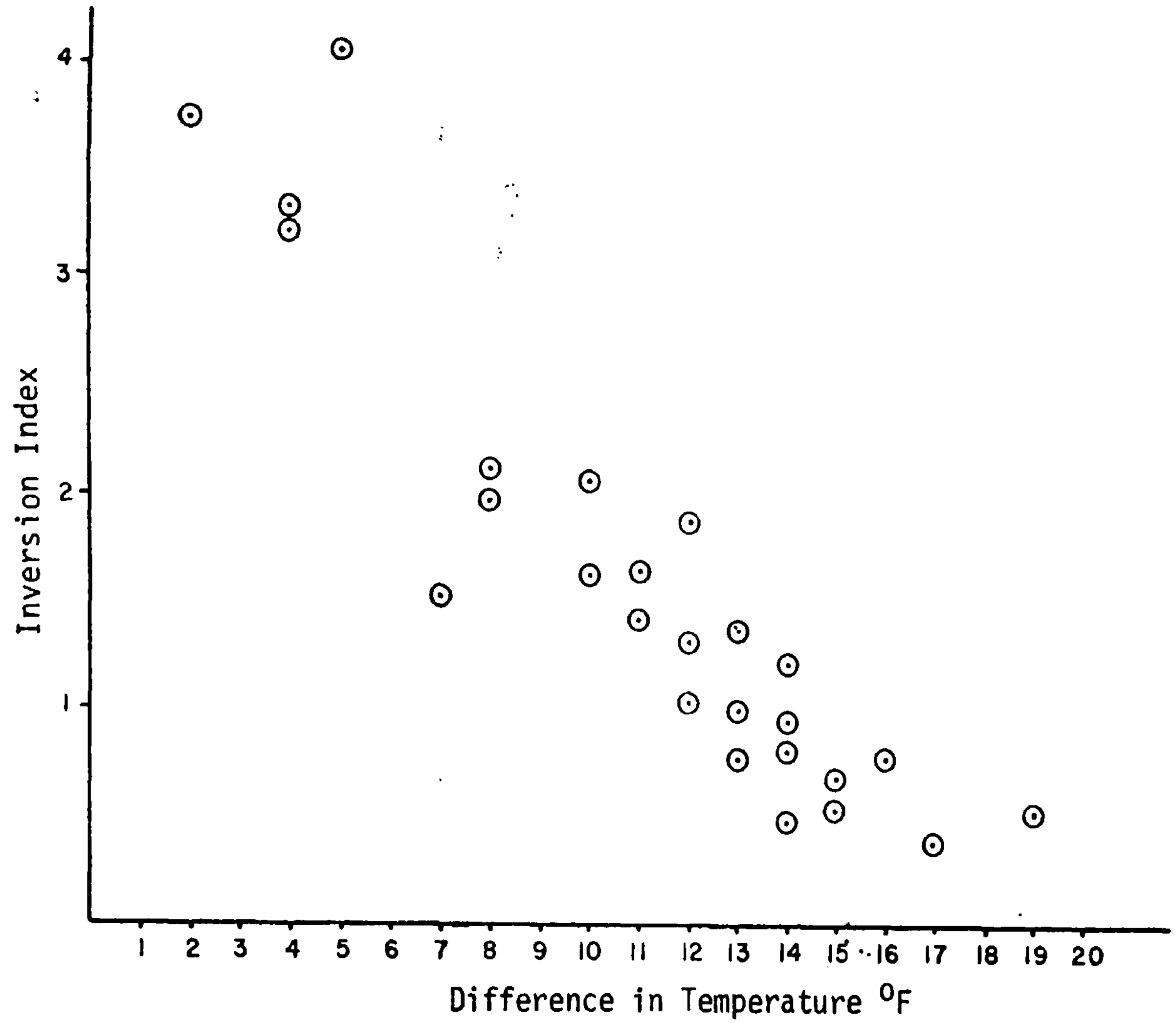

Figure 3.9

Monthly Inversion Index Versus Monthly Average Difference in Temperature, T.V. Mountain - Missoula County Airport 1200 M -- Sep. 1969 - Dec. 1971.

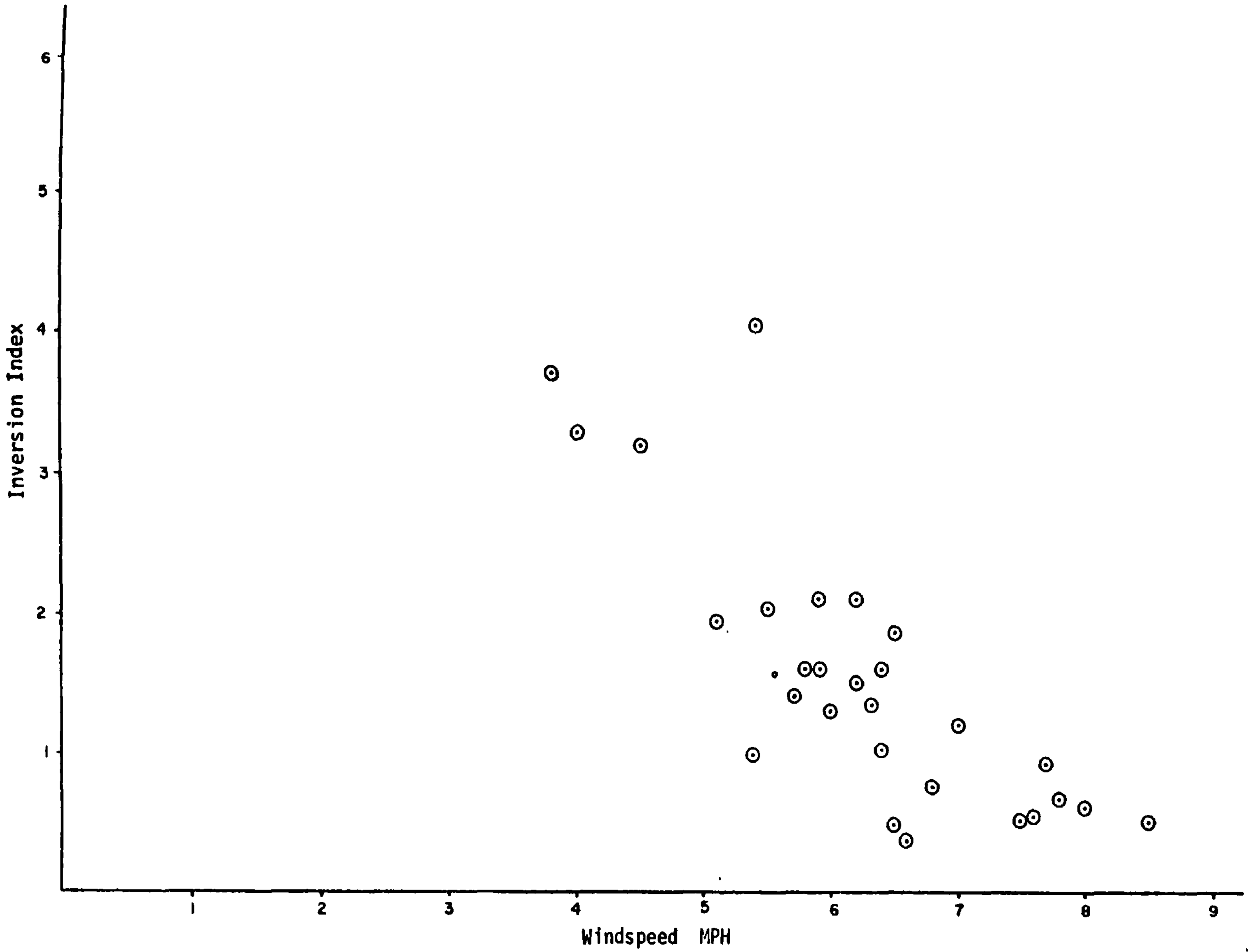

Figure 3.10

Monthly Inversion Index Versus Monthly Average Wind Speed at the Missoula County Airport, Sep. 1969 - Dec. 1971.

PERCENT FREQUENCY OF NIGHTTIME SURFACE WIND 7 mph OR LESS

	Winter*	Spring	Summer	Fall
Billings	27	35	38	35
Great Falls	18	26	32	27
Helena	69	63	67	69
Missoula	81	68	76	86

*Winter, Jan.-Mar.; Spring, Apr.-June; Summer, July-Sept.; Fall, Oct.-Dec.; incl. From MWR, Vol. 89, No. 9, pp. 333, 335, and 336; Charles R. Hosler.

PERCENTAGE FREQUENCY OF ALL WIND OBSERVATIONS WITH SPEEDS 7 mph OR LESS

	Winter	Spring	Summer	Fall	Year
Billings Airport	25	31	36	29	31
Butte Airport	64	48	58	64	58
Gt. Falls Airport	22	25	36	22	26
Helena Airport	63	51	63	70	62
Missoula Airport	73	62	70	83	72

AVERAGE ANNUAL WIND SPEEDS ALL SOURCES (mph)

Billings Airport	11.3	Helena Airport	7.9
Butte Airport	7.8	Kalispell (City)	5.9
Gt. Falls Airport	14.4	Kalispell Airport	7.6
Havre(City*)	8.2	Miles City (City)	10.1
Helena(City)	7.9	Missoula Airport	5.9

*Anemometer exposure somewhat sheltered.

Figure 3.11

Montana Potential Inversion Conditions (from A Study of Air Pollution in Montana, State Department of Health, July 1961 - July 1962).

however, it is assumed that wind speeds greater than 7 mph will prevent strong inversions from occurring. We can see from figure 3.11 that Missoula has a very high inversion potential based on wind speed.

Figure 3.8 shows that the annual inversion index for Missoula has dropped considerably in 1970 and 1971. A corresponding rise in the annual average wind speed has also been noted. Annual average particulate levels in Missoula have also dropped noticably during this time period. It is certainly conceivable that much of the decrease in particulate levels noticed in Missoula is due to the decrease in frequency and persistence of inversions in the valley.

The second variable we will consider is atmospheric water vapor. Water can exist in all three physical states in the atmosphere. We shall first be concerned with gaseous water. Atmospheric water vapor is measured in several different ways. One method used to determine the amount of water vapor present in the atmosphere is to measure the contribution of water vapor to the total atmospheric pressure. The contribution of water vapor is called the partial pressure due to water vapor or more simply the vapor pressure. When the atmospheric water vapor reaches equilibrium with liquid water the saturation vapor pressure is reached. The atmospheric temperature at saturation is called the dew point. The actual amount, or weight of water in a given volume of air is called the absolute humidity. The ratio of the actual atmospheric vapor pressure to the saturation vapor pressure at a given temperature is called the relative humidity. Relative humidity can range from 0 to 100 percent.

There are several sources of atmospheric water vapor, however, they can be classified into four general types: evaporation from any moist surface or body of water, evaporation from the soil, transpiration from plants and combustion. Oceans are obviously the most important source of atmospheric water vapor since they cover more than three fourths of the Earth's surface. Plants also contribute a great deal of atmospheric moisture, as much as eight times more than a comparable area of bare ground. The contribution to atmospheric water vapor from human activities is generally considered negligible, however, in certain areas this is far from true. The combustion process is a major contributor of atmospheric water vapor and certain industrial processes are also large contributors. In the Missoula Valley a Kraft pulp mill discharges large quantities of water vapor daily. A Kraft process pulp mill in Lewiston, Idaho producing 650 tons of pulp per day, about 55 percent of the current Hoerner-Waldorf production, emitted 1,113,400 gallons of water per day in 1961.[43] According to a report issued by the Hoerner-Waldorf Corporation in 1969 if all of the water vapor discharged from the mill in a year condensed at once and fell as rain it would provide approximately one half of an inch of rainfall in the Missoula Valley.[44] The surface area considered to be the Missoula Valley was not deliniated. It is interesting to note, however, that one half an inch of rainfall is about four percent of the total annual average rainfall recorded at the Missoula County Airport.

The annual average relative humidity recorded at the Missoula County Airport is shown in figures 3.12 to 3.15. Relative humidity is currently reported at 500, 1100, 1700 and 2300 M. Until 1957 the relative humidity was reported at 530, 1130, 1730, and 2330 M. The annual average relative humidity for Spokane and Kalispell are also shown in figures 3.12

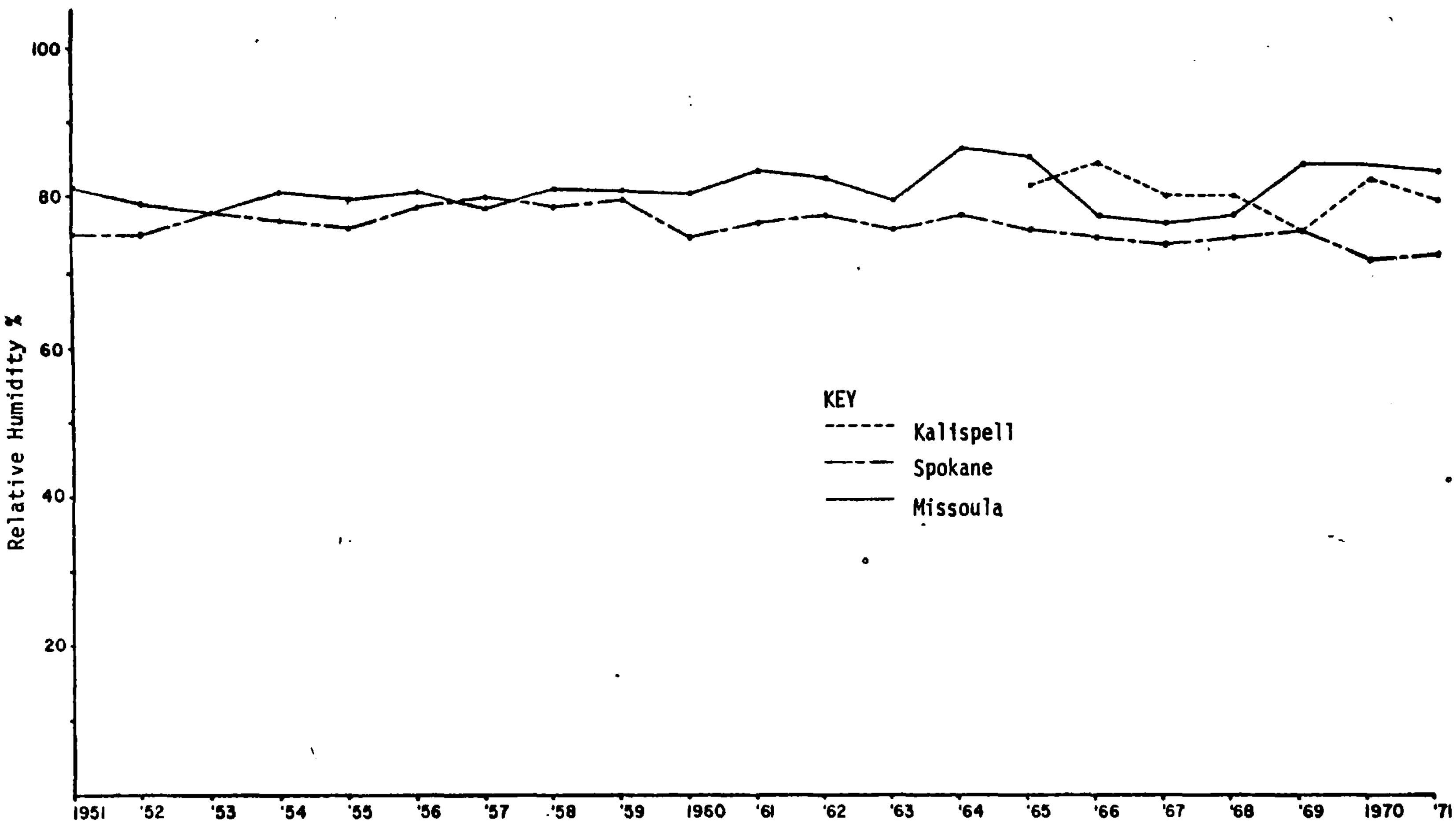

Figure 3.12

Annual Average Relative Humidity at Missoula, Kalispell, Spokane 0500 M -- 1951 - 1971.

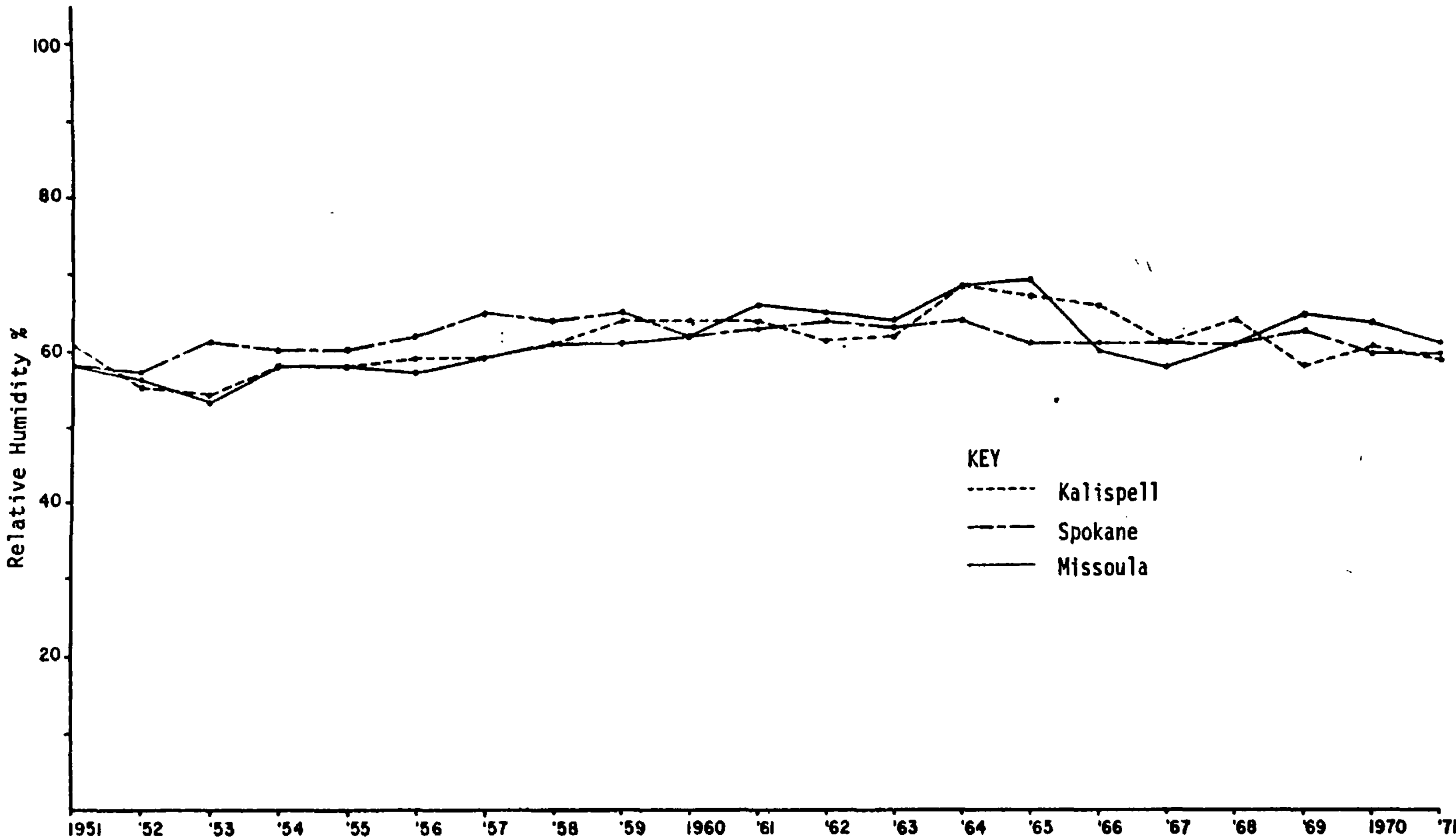

Figure 3.13

Annual Average Relative Humidity at Missoula, Kalispell, Spokane 1100 M -- 1951 - 1971.

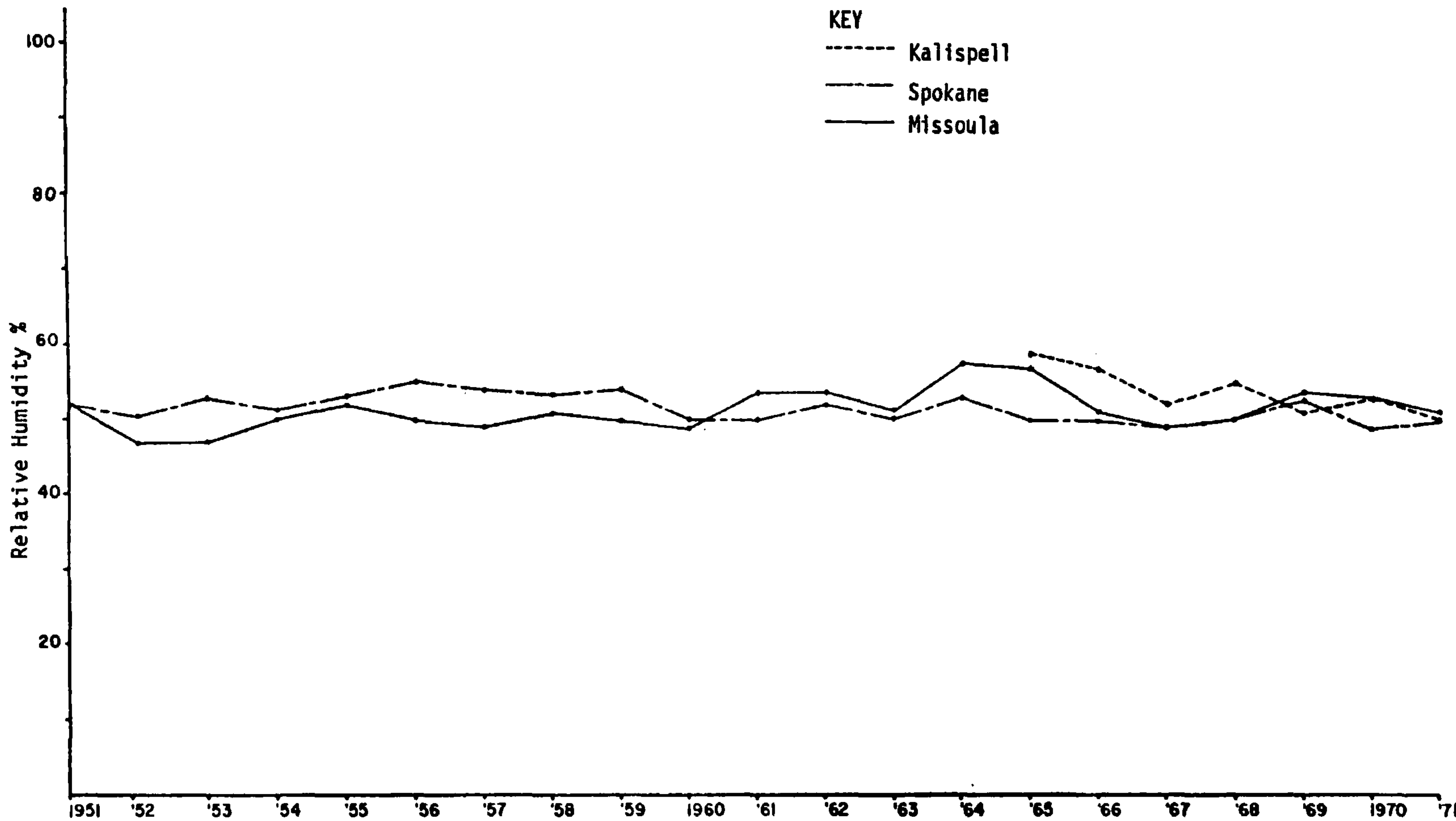

Figure 3.14

Annual Average Relative Humidity at Missoula, Kalispell, Spokane 1700 M -- 1951 - 1971.

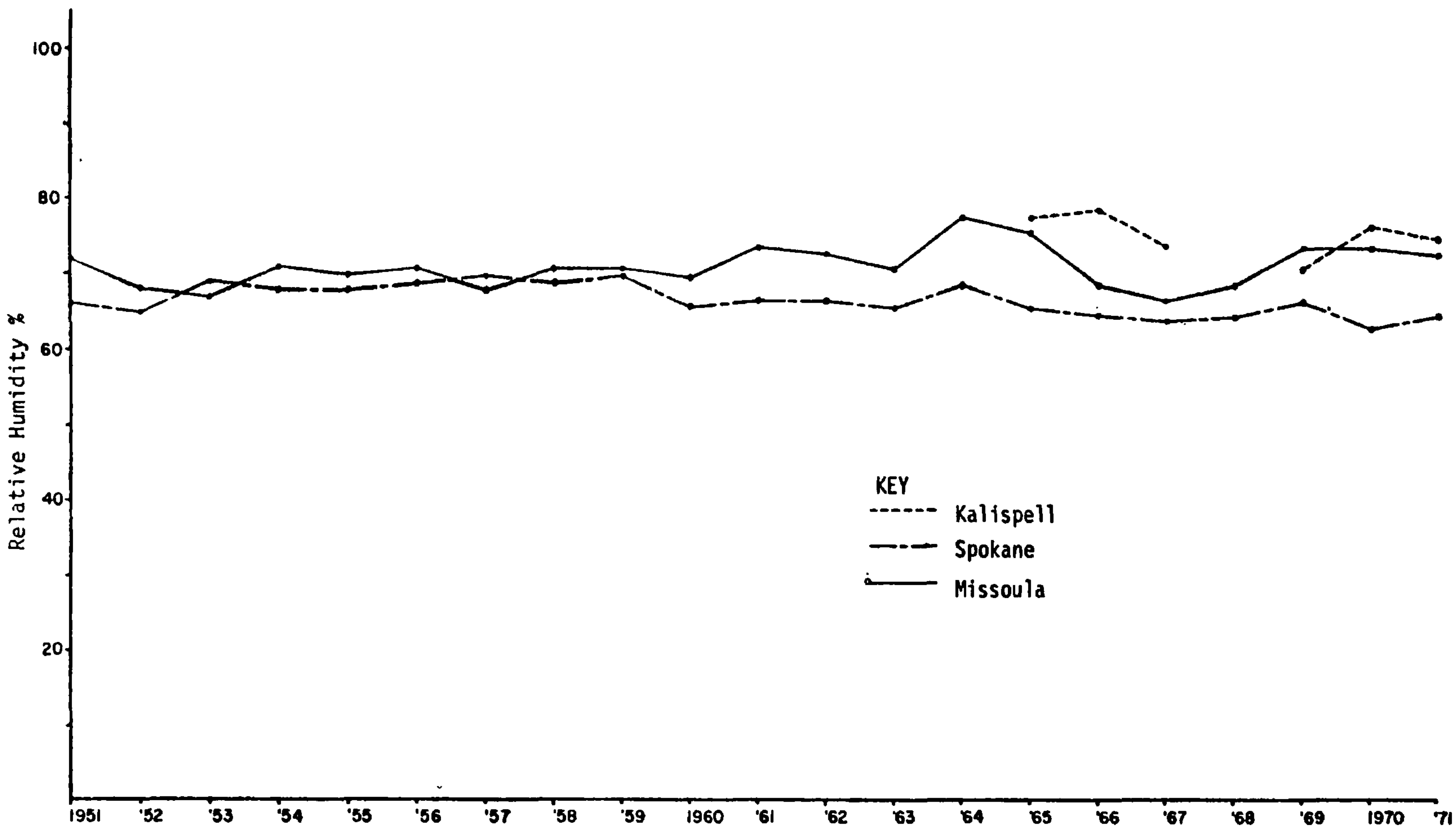

Figure 3.15

Annual Average Relative Humidity at Missoula, Kalispell, Spokane 2300 M -- 1951 - 1971.

to 3.15. The relative humidity in the Missoula Valley has increased noticeably in the twenty year period since 1951. In 1956 the "normal" annual relative humidity at 1130 M was 59 percent based on twelve years of data. In 1970 the "normal" annual relative humidity at 1100 M was 64 percent based on ten years of data. Relative humidty observations at the other times also show an increase. The relative humidity at the Kalispell airport, 8.5 miles northeast of Kalispell, also shows an increase which parallels the increase noted at Missoula. The relative humidity recorded at the Spokane Airport appears to be more constant over time. One factor which is responsible for some of the increase in relative humidity is the time change in recording the relative humidity. Beginning in 1957 all observations were made one half hour earlier. Assuming a linear decrease in relative humidity between 0530 and 1130, observing relative humidity at 1100 rather than 1130 would cause an increase in relative humidity of almost two percentage points. It would seem logical that the introduction of a Kraft process pulp mill into the Missoula Valley would be another cause of increased relative humidity. It is interesting to consider the 1100 M relative humidity, the observation that has shown the most dramatic increase. As can be seen from figure 3.13, during the period from 1951 to 1960 the Missoula annual average relative humidity at 1100 M was less than or equal to the Kalispell relative humidity in nine of the ten years. Similarly the Missoula relative humidity was less than or equal to the Spokane relative humidity for all ten years. For the period from 1961 to 1970, however, the Missoula relative humidity was greater than the Kalispell relative humidity during seven of the ten years, and greater than the Spokane relative humidity during eight of the ten years. The three other relative humidity observations have been made at Kalispell only since 1965, however, Spokane has continuous data through the period. For the 1700 M observation the Missoula relative humidity was less than or equal to the Spokane relative humidity for all ten years during the period 1951 to 1960. The Missoula relative humidity was greater than or equal to the Spokane relative humidity for all ten years during the period 1961 to 1970. The other two observations do not show such an obvious trend, however, the average difference between Spokane and Missoula relative humidity values at these times has obviously increased.

It certainly appears possible that the pulp mill has influenced the daytime relative humidity values. The pulp mill was located in Missoula in 1957 and beginning in 1961 production increased from 250 to 600 tons per day.[45] More detailed statistical analysis appears to be necessary to substantiate conclusively that the increase in relative humidity in the valley is due to anthropogenic water vapor It is certainly puzzling that the drop in relative humidity during the period from 1966 through 1968 corresponds to a period when the Hoerner-Waldorf production increased from 600 tons per day to 1150 tons per day. A drop in relative humidity of nine percentage points or thirteen percent between 1965 and 1966 is certainly unusual especially when accompanied by a 92 percent increase in Hoerner-Waldorf production.[45]

Urbanization is also known to effect relative humidity. While the absolute humidities of adjacent rural and urban areas may be similar, the relative humidity of an urban site is generally several percent lower than a corresponding rural location. The main cause of this phenomena is the rural-urban "heat island" effect, Since relative humidity is inversely temperature dependent, the increased temperature associated with urban locations will correspond to a decrease in relative humidity.

The role of human activities in the modification of atmospheric precipitation is interesting and presently quite controversial. The general thought is that human activities and urbanization increase precipitation. The classic study of Changnon at La Porte, Indiana is often cited as an example.[46] Changnon demonstrated a very large increase in precipitation, thunderstorms, and hail at La Porte, Indiana since 1925. He associates this increase with the rapid industrialization of the Chicago-Gary. Indiana area approximately thirty miles upwind from La Porte. There is a general agreement between the annual number of smoke-haze days in Chicago and the annual precipitation level recorded at La Porte. Changnon believes that high concentrations of ice nuclei from the steel mills and added heat from industrial sources are responsible for the precipitation anomoly.[47]

Several other authors have reported increased precipitation in urban areas. Landsberg has concluded that a city will receive about ten percent more precipitation than adjacent rural areas. Dettwiller also has shown that urban areas receive more precipitation. Dettwiller reported that from 1953 to 1967 Paris, France received 31 percent greater rainfall on weekdays than weekends. The implication of this data is that the increased activity of the city during the five day work week leads to increased precipitation. Increased thunderstorms over urban areas have also been reported by numerous authors.[36]

The consensus is that cities are an excellent source of ice and condensation nuclei which modify cloud formation and precipitation patterns. The effect of these nuclei in precipitation formation is not presently completely understood. The optimum concentration of these nuclei necessary for modifying precipitation patterns has not yet been determined. In fact, under some circumstances a reduction in precipitation may occur with an increase in condensation nuclei When large numbers of condensation nuclei are introduced into warm clouds large drops are not formed, coalescence is ineffective and precipitation is inhibited. As an example of this phenomena Warner has reported a twenty-five percent decrease in precipitation in Eastern Australia which he attributes to an increase in smoke due to sugar cane burning in the last fifty years.[50]

The annual average precipitation at the Missoula County Airport and the Missoula 2WNW station are shown in figure 3.16. There is no apparent trend in the total precipitation levels at the two stations. For the period from 1951 to 1960 the annual average precipitation at the Airport station was 13.49 inches and at the 2WNW station was 13.54 inches. The 1960 normals for the two stations are 12.83 at the Airport and 12.78 at 2WNW. The number of days per year with precipitation greater than .01 inches for the Missoula 2WNW and Airport stations are shown in figure 3.17. It is interesting to note that the number of rainy days per year decreases as we move from the rural airport location to the 2WNW station. The Airport station averaged 8.5 more rainy days per year than the 2WNW station, while the 2WNW station received more total rainfall. The Missoula station had the highest number of rainy days per year during the four years when all three stations were operating

YEAR	MISSOULA 2WNW	MISSOULA COUNTY AIRPORT	MISSOULA CITY
1965	15.61	14.20	--
1964	17.56	15.22	--
1963	14.55	14.89	--
1962	12.63	11.99	--
1961	15.70	14.10	--
1960	9.89	9.87	--
1959	16.15	16.29	--
1958	15.52	16.98	--
1957	11.55	12.21	--
1956	16.43	15.16	--
1955	17.23	15.82	--
1954	14.72	13.60	--
1953	10.99	11.36	--
1952	8.02	8.62	--
1951	15.04	15.02	--
1950	12.89	14.18	--
1949	10.01	8.94	--
1948	15.87	14.87	--
1947	16.19	14.68	--
1946	12.97	12.43	--
1945	11.02	9.78	--
1944	12.87	10.59	13.22
1943	14.45	13.61	15.71
1942	15.61	14.99	14.89
1941	16.82	16.19	15.79
1940	12.03	10.42	12.32

Figure 3.16

Average Annual Precipitation for Missoula 2WNW, Missoula County Airport, & Missoula City Stations.

YEAR	MISSOULA 2WNW	Δ	MISSOULA COUNTY AIRPORT	Δ	MISSOULA CITY
1971	--	-	137	-	-
1970	--	-	132	-	-
1969	--	-	103	-	-
1968	--	-	136	-	-
1967	--	-	126	-	-
1966	--	-	107	-	-
1965	128	-7	121	-	-
1964	124	7	131	-	-
1963	114	7	121	-	-
1962	104	6	110	-	-
1961	114	24	138	-	-
1960	115	-3	112	-	-
1959	141	-1	140	-	-
1958	129	3	132	-	-
1957	129	3	126	-	-
1956	121	5	126	-	-
1955	129	12	141	-	-
1954	116	3	119	-	-
1953	104	17	121	-	-
1952	88	6	94	-	-
1951	113	20	133	-	-
1950	122	27	149	-	-
1949	90	17	107	-	-
1948	113	3	116	-	-
1947	96	28	124	-	-
1946	100	11	111	-	-
1945	104	23	127	-	-
1944	88	8	96	-	-
1943	108	-4	104	11	115
1942	118	10	128	1	129
1941	129	1	130	7	137
1940	120	2	122	15	137
Average Difference		= 8.5+		= 8.5+	

Figure 3.17

Number of Days per Year with Precipitation Greater than .01 Inches for Missoula 2WNW, Missoula County Airport, and Missoula City Stations.

simultaneously. Figure 3.18 gives the number of days per year with precipitation greater than .10 inches. There is no apparent trend in days with precipitation greater than .10 inches.

Human activities have also been considered to be responsible for an increase in the number of thunderstorms in certain locations. The primary example of this circumstance is the La Porte, Indiana precipitation anomoly. Changnon has reported a 38 percent increase in the annual number of thunderstorms reported at La Porte during the period from 1951 to 1965. The annual number of thunderstorms during the period from 1955 to 1971 for Missoula, Kalispell, and Spokane are shown in figure 3.19. There does not appear to be any trend in the number of thunderstorms reported at Missoula. In the northern Rocky Mountain region topography is probably the major factor influencing thunderstorm occurrence.

In 1969 Thomas E. Horobik studied the precipitation patterns of six western Montana locations. Horobik demonstrated that for the comparison periods of 1940 to 1957 and 1958 to 1969 the total annual precipitation had decreased in Darby, Hamilton, Polson, and Stevensville and had increased in Missoula and St. Ignatius. 1957 was choosen to separate the two periods because of the introduction of the pulp mill into the Missoula area. Horobik believes that the introduction of hygroscopic nuclei and water vapor have caused the increase in precipitation at Missoula and St. Ignatius. He concludes that the increased rainfall in St. Ignatius is due to the combination of water vapor from Flathead Lake and hygroscopic nuclei from a lumber mill in Polson. The Missoula 2WNW station is not included in Horobik's paper The station was removed in 1966, however, the increasing precipitation trend

YEAR	MISSOULA 2WNW	MISSOULA COUNTY AIRPORT	Δ
1965	48	47	1
1964	48	42	6
1963	47	50	-3
1962	38	39	-1
1961	44	47	-3
1960	34	34	0
1959	55	54	1
1958	52	56	-4
1957	37	40	-3
1956	47	44	3
1955	51	49	2
1954	46	42	4
Average Difference			= 0

Figure 3.18

Number of Days per Year with Precipitation Greater than .10 Inches for Missoula 2WNW, and Missoula County Airport Stations.

YEAR	MISSOULA	KALISPELL	SPOKANE
1955	23	17	8
1956	26	33	10
1957	27	28	18
1958	37	29	24
1959	18	18	11
1960	14	17	8
1961	25	28	12
1962	28	16	16
1963	33	29	12
1964	14	18	14
1965	24	19	8
1966	31	30	8
1967	20	19	12
1968	15	--	2
1969	16	18	9
1970	21	20	11
1971	23	22	6

Figure 3.19

Annual Number of Thunderstorms at Missoula, Kalispell, and Spokane, 1955 - 1971.

is apparent with this station also. The average precipitation for the Missoula 2WNW station during the 1940-1957 period was 13.60 inches while the 1958-1965 average was 14.70 inches. The Missoula Airport annual average precipitation for the 1958-1965 period was 14.19 inches.

While it may be logical to conclude that industrial water vapor and hygroscopic nuclei are responsible for the increase in precipitation in the Missoula Valley there are certainly unanswered questions in this approach. Although large quantities of nuclei are undoubtably present in Missoula it is debatable whether these nuclei would enhance or suppress precipitation. The specific chemical composition of the nuclei, the size, and the number of nuclei present all control the rate of precipitation formation. Site changes within the study period can also have a large effect on precipitation trends. The Missoula, Stevensville, Hamilton, and St. Ignatius station locations were not altered significantly during the period of Horobik's study. The Darby station was moved two miles SSE in 1957. The elevation gain accompanying this change was 65 feet. The Polson station was moved several times in the period from 1953 to 1965 and was finally closed in May 1966. The data which Horobik presents for the Polson station after May 1966 were apparently taken from the Kerr Dam site approximately five miles southwest of Polson in a canyon. The elevation of the Kerr Dam station is about 200 feet lower than the station at Polson. A great deal of the decrease in precipitation recorded at the Polson station during the 1958-1969 period could be due to this site change.

In an attempt to determine the statistical significance of the precipitation increase recorded at the Missoula County Airport the precipitation records of all the stations west of the Continental Divide in

Montana were studied. Two averages were determined for each station, a pre and post pulp mill average. For each station the pre pulp mill average was the mean of the annual average precipitation values for the years 1944 to 1957, a period of fourteen years. Similarly the post pulp mill average was the mean of the annual average precipitation values for the years 1958 to 1971, a fourteen year period. The pulp mill was constructed in Missoula in 1957 The only sites included in the study were those that had not moved significantly during the period of the study. We considered a significant move to be a change of altitude of more than 100 feet or a linear move of more than two minutes latitude or longitude. A total of twenty stations had data which met our critera. Figure 3.20 gives pre and post pulp mill means for the twenty stations and the differences between the two means. The differences between the pre and post pulp mill means are also plotted on a map of the state of Montana in figure 3.21. The increase in precipitation recorded at Missoula does not appear to be statistically significant. Because of the wide fluctuation in the precipitation differences detailed statistical analysis was considered futile. Figure 3.22 shows that the stations with an increase in precipitation are all contiguous. The significance and interpretation of this data is beyond the scope of this study.

The role of air pollution in modifying the incidence of fog has been studied in several locations and has been confirmed to the satisfaction of most atmospheric scientists. Fog is more frequent in urban, industrial centers than in surrounding rural locations. With relative humidities in excess of 70 percent, various types of atmospheric particulate are deliquescent and can grow into fog droplets.

STATION	MEAN 1943-1957	MEAN 1958-1971	Δ	CHANGE
Bigfork 13S	22.03	23.18	1.15	+
Heron	34.64	35.27	0.63	+
Thompson Falls	21.56	24.56	3.00	+
Haugan	33.15	31.73	-1.42	-
Superior	17.95	18.07	0.12	+
Fortine	18.81	17.48	-1.33	-
Libby	18.62	18.60	-0.02	-
West Glacier	29.79	31.15	1.36	+
Summit	40.03	39.89	-0.14	-
Kalispell City	14.75	15.93	1.18	+
Seeley Lake	21.43	23.85	2.42	+
Ovando 1SW	15.78	16.96	1.18	+
Butte Airport	12.16	11.93	-0.23	-
East Anaconda	13.85	14.25	0.40	+
Phillipsburg	15.83	13.59	-2.24	-
St. Ignatius	15.73	16.82	1.09	-
Stevensville	13.38	12.74	-0.64	-
Hamilton	12.99	12.83	-0.16	-
Darby	16.61	15.45	-1.16	-
Missoula AP	12.66	13.67	1.01	+

Figure 3.20

Pre and Post Pulp Mill Precipitation

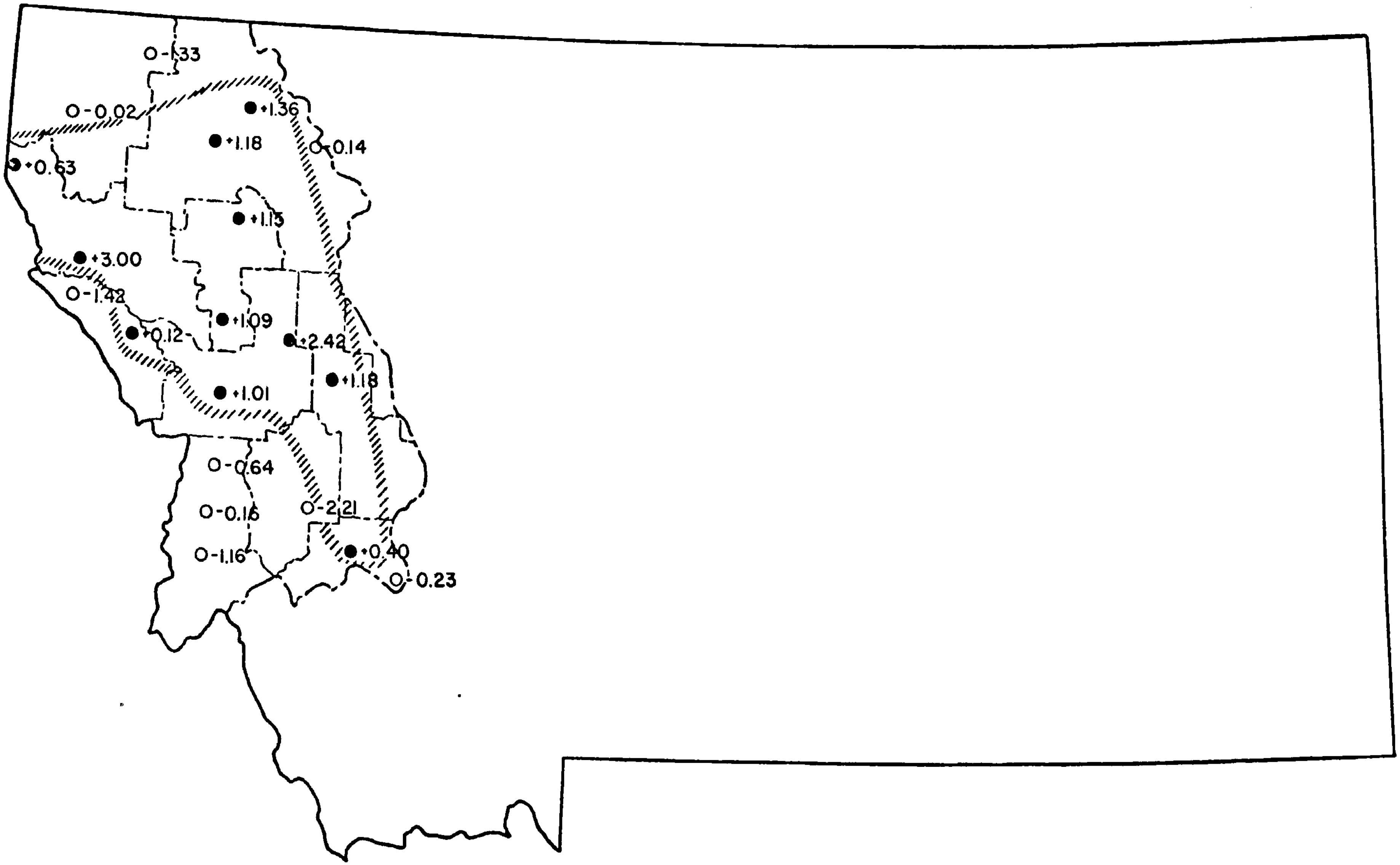

Figure 3.21

Difference Between Pre and Post Pulp Mill Precipitation Means.

The number of days per year with heavy fog at the Missoula County Airport has increased during the last twenty years. Heavy fog is defined by United States Weather Bureau Standards to be fog which restricts prevailing visibility to one quarter mile or less. The prevailing visibility is the greatest visibility which is attained in at least one half of the horizon circle, not necessarily continuous. In August 1966 Richard A. Dightman, the State Climatologist, published a paper "A Comparison of Fog Incidence at Missoula, Montana with Surrounding Locations."[3] Dightman compared the annual incidence of heavy fog at Missoula with the annual incidence of heavy fog at Spokane, Helena, and Great Falls. Dightman demonstrated that the increase in fog at Missoula was statistically significant. Using double mass analysis Dightman demonstrated that the abnormal increase in fog began in 1958, the first full year of operation of the pulp mill in Missoula. Rudolf Honkala disputed these findings in a letter to Dan Potts of the Hoerner-Waldorf Corporation in March of 1969. Honkala suggested that Dightman's results were invalid because his comparison stations were not climatologically similar Honkala suggested that Kalispell, Lewiston, Idaho, and Salt Lake City, Utah would be reasonable comparison stations.

In this paper we have extended Dightman's calculations through 1971. Honkala's suggestions concerning sampling locations were considered. We rejected the Salt Lake City comparison location because of the very large urban influences present there. Lewiston, Idaho was rejected because of the pulp mill present in the valley. Kalispell was accepted as a comparison location, however, missing data made statistical comparison impossible. Figure 3.22 shows the annual number of days with heavy fog recorded at

YEAR	MISSOULA	KALISPELL	HELENA	GREAT FALLS	SPOKANE
1950	28	44	10	14	47
1951	20	40	6	18	38
1952	29	30	11	8	52
1953	20	--	8	4	30
1954	27	--	8	8	43
1955	21	--	6	14	49
1956	18	--	3	12	51
1957	21	--	8	17	50
1958	48	--	7	11	60
1959	33	--	2	12	46
1960	29	34	7	13	45
1961	32	24	1	10	44
1962	41	32	12	16	65
1963	35	26	7	11	53
1964	29	45	5	4	47
1965	55	36	15	15	57
1966	23	38	3	7	54
1967	26	15	4	17	35
1968	30	--	12	9	46
1969	44	43	24	18	77
1970	26	35	3	22	47
1971	19	24	5	15	49

Figure 3.22

Annual Number of Days with Heavy Fog -- Missoula, Kalispell, Helena, Great Falls, Spokane.

Missoula, Spokane, Kalispell, Helena, and Great Falls during the period from 1950 to 1971. Figure 3.23 gives a comparison of the change in the mean number of heavy fog days at Missoula, Helena, and a three station mean of Helena, Great Falls, and Spokane. Dightman concluded in 1966 that the increase in fog at Missoula was statistically significant; extension of his calculations through 1971 does not alter this conclusion. Figure 3.24 is a double mass plot of the accumulated annual number of days with fog at Missoula versus the accumulated three station mean. The trend discovered by Dightman appears to continue through 1971. The change in slope which began in 1958 indicates that the change in fog incidence at Missoula did not occur at the other three stations. The introduction of the pulp mill with its associated particulate and water vapor in 1957 is certainly a possible causative agent.

Deterioration of visibility is also associated with human activities. Visibility or visual range is considered to be the distance at which it is just possible to perceive an object against the horizon sky. Reduction in visibility can be caused by atmospheric particulate and aerosols. The visible radiation passing from object to observer is attenuated. The attenuation is the result of absorption of light and the scattering of light out of the incident beam, thus the eye's ability to distinguish an object from its background is reduced. Visibility can also be reduced through the illumination of the air between the object and the observer. This illumination is caused by the scattering of sunlight by particulate and aerosols into the line of sight.[7]

There has been a controversy over the interpretation of visibility statistics in the Missoula Valley. Detailed visibility studies have been

	Missoula	Helena	3 Stations Mean
1950-1957 mean	23.00	7.50	21.50
1958-1971 mean	33.57	7.64	23.36
Difference	10.57	0.14	1.86

Figure 3.23

Comparison of Heavy Fog Days

performed by Ed Nelson, head meteorologist at the Missoula Weather Station, Rudolph Honkala, and Gary Jensen. Honkala presented a detailed visibility study for the period from 1950 to 1968. In preparation for this paper Gary Jensen continued Honkala's work through 1971. The reader is referred to Honkala and Jensen's papers for a detailed analysis of visibility patterns in the Missoula Valley. A general summary of visibility patterns in the Missoula Valley for the period 1950 to 1971 is shown in figures 3.25 and 3.26. Reduced visibility caused by precipitation is included in these figures. Similar calculations by Ed Nelson which eliminate reduced visibility due to precipitation show an identical trend. We again note a dramatic increase in reduced visibility in the Missoula Valley beginning in 1958, the first full year of pulp mill operation. Increased pulp mill production in 1966 does not correlate with decreased visibility however.

One of the major factors influencing visibility in the Missoula Valley is inversion frequency and strength. Figures 3.27 and 3.28 show the relationship between the annual average inversion index and the number of hours per year with six and three mile visibility from 1965 to 1971. With the exception of 1965 a nearly linear relation exists between the annual inversion index and reduced visibility. This relation should

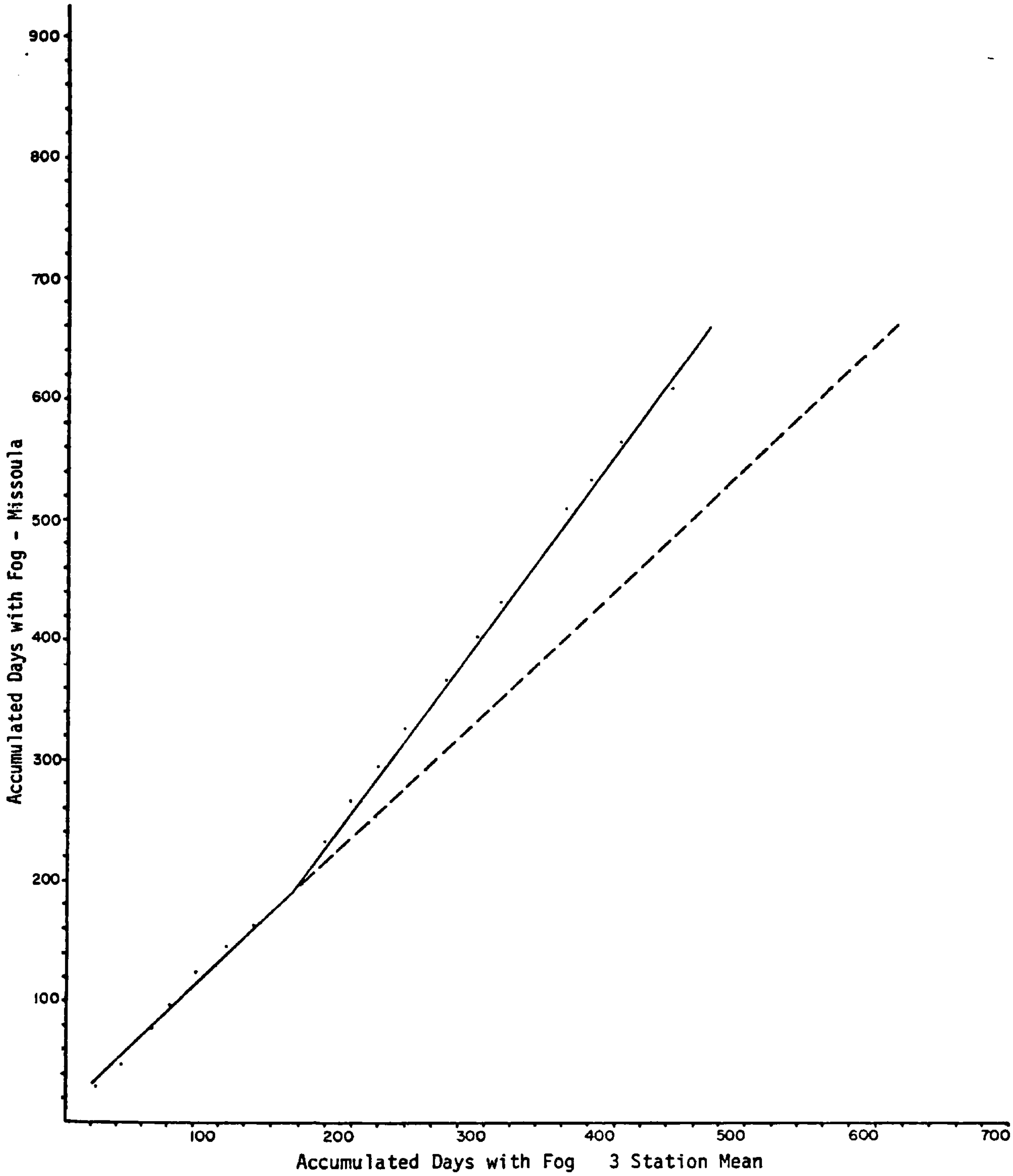

Figure 3.24

Double Mass Analysis of Fog Data - Missoula, Helena, Great Falls, Spokane.

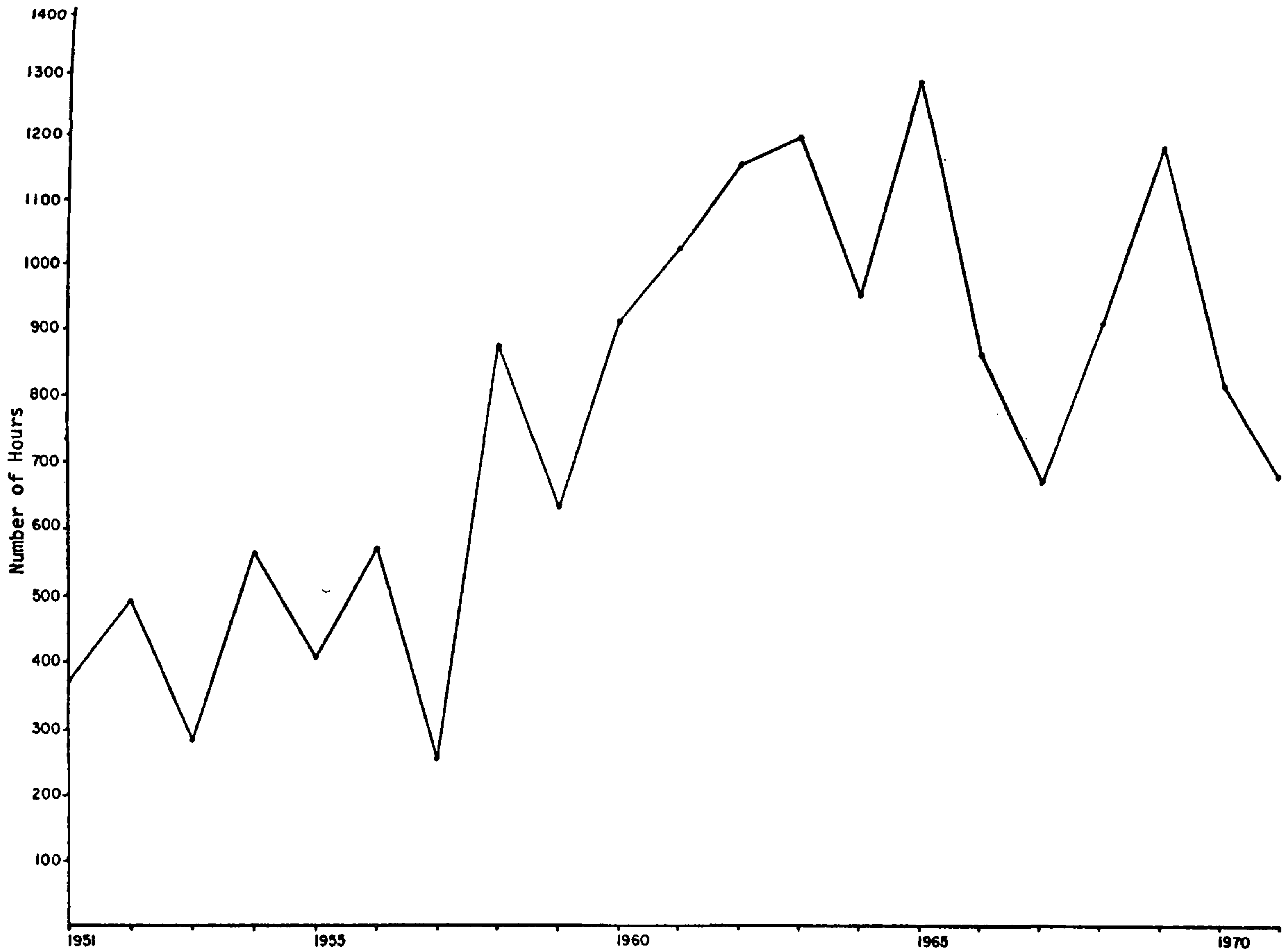

Figure 3.25

Number of Hours per Year with Visibility 6 Miles or Less at the Missoula County Airport.

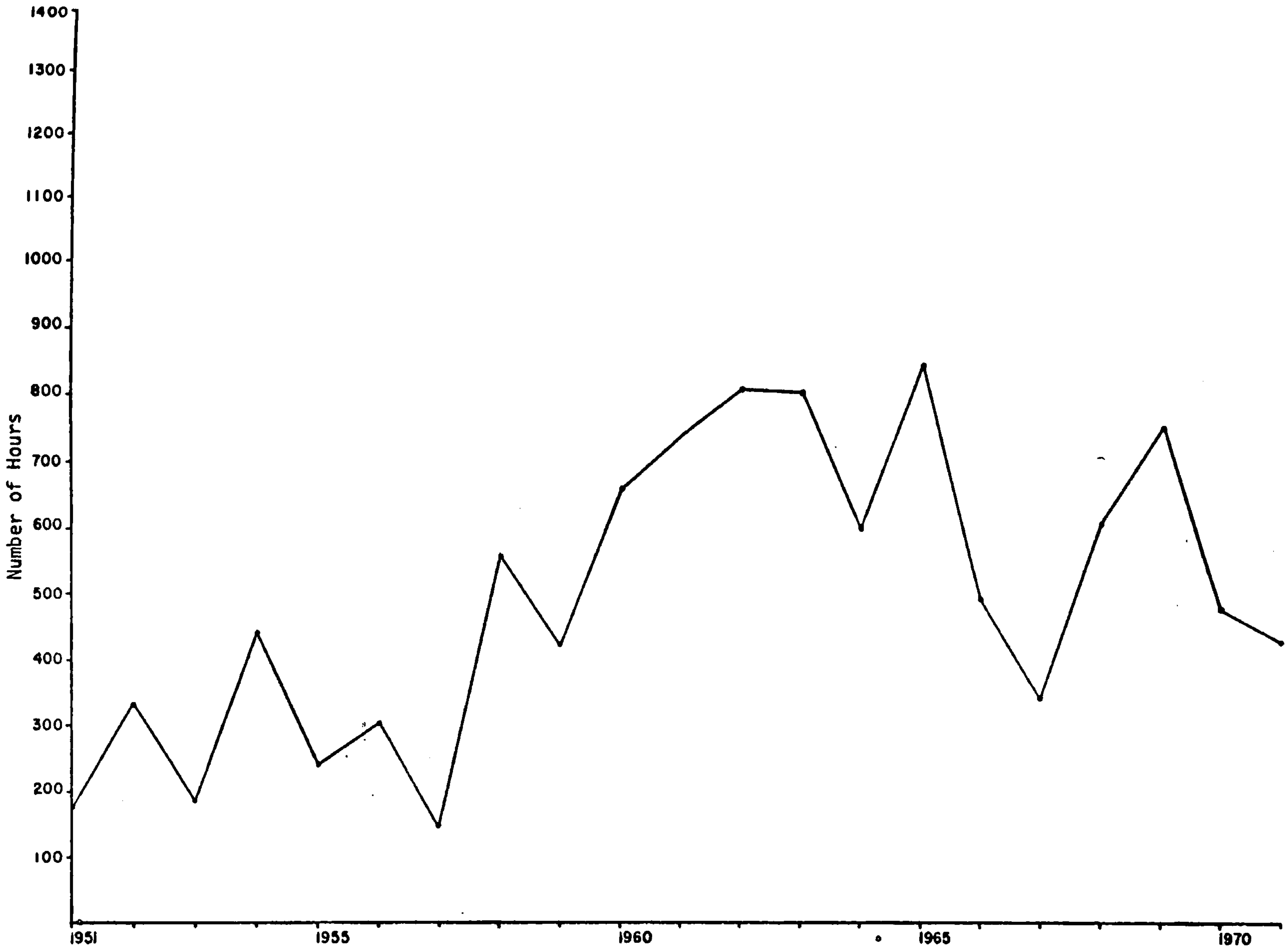

Figure 3.26

Number of Hours per Year with Visibility 3 Miles or Less at the Missoula County Airport.

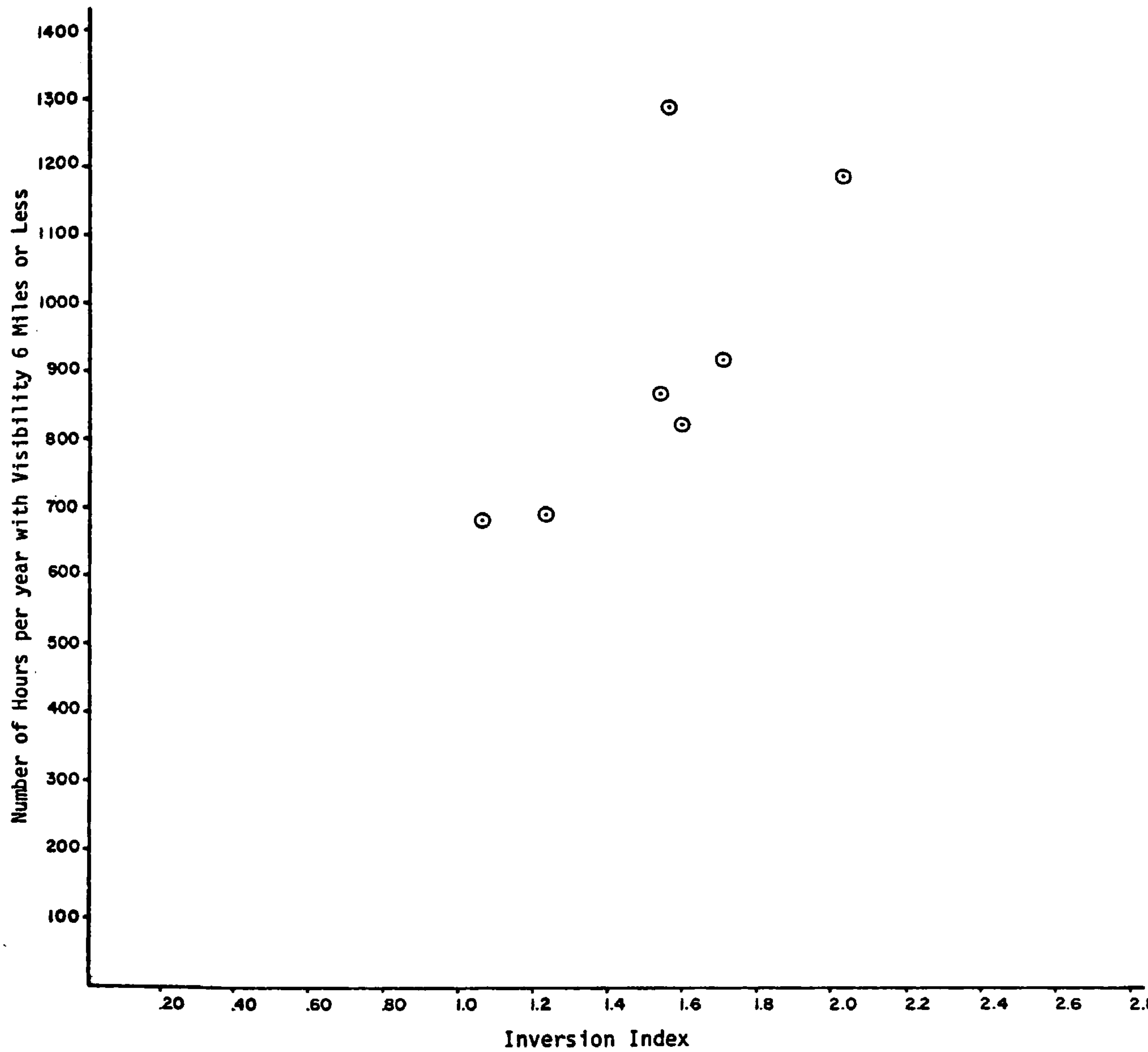

Figure 3.27

Annual Inversion Index Versus 6 Mile Visibility at the Missoula County Airport.

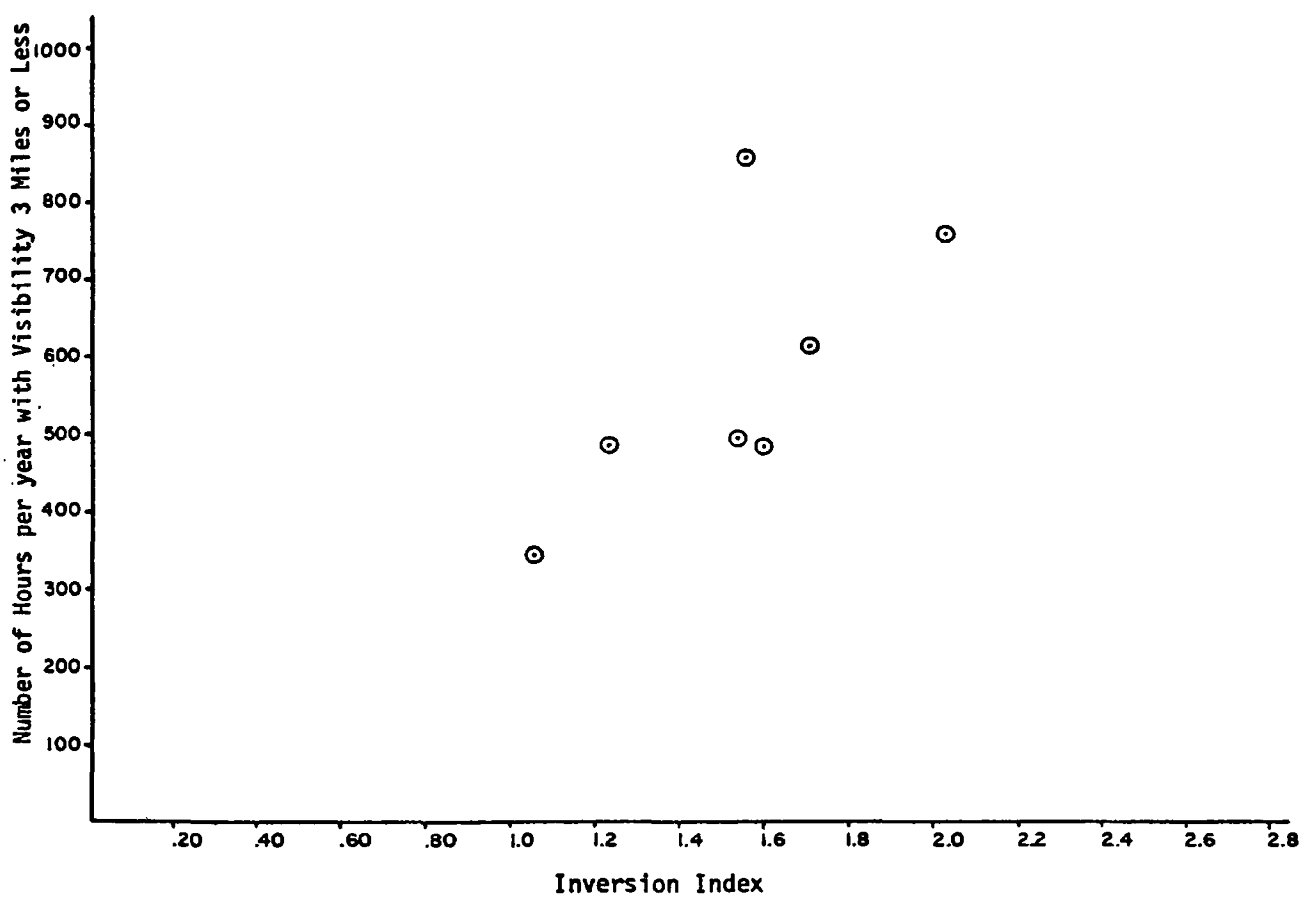

Figure 3.28

Inversion Index Versus 3 Mile Visibility at the Missoula County Airport.

certainly be expected since inversions create conditions of atmospheric stagnation. Under atmospheric stagnation pollutants, especially particulates, accumulate and lead to attenuation of visible radiation and reduction of visibility. The reduction in particulate levels since 1969 is reflected in increased visibility in the Missoula Valley.

An increase in atmospheric water vapor and particulate could also effect cloud cover. Increased water content and nuclei could lead to an increase in cloud formation through coalescence and condensation. Figure 3.29 shows the average sky cover from sunrise to sunset for Missoula for the period from 1951 to 1971. Sky cover is given a rating from 0 to 10. A rating of 0 is a completely clear sky while 10 is entirely overcast. Clear days have a sky cover rating of 0 to 3, partly cloudy days range from 4 to 7, and higher ratings are considered cloudy. There is no apparent trend in sky cover in the Missoula Valley. Because of the nature of the rating scale any increase in sky cover would have to be quite dramatic before it would be evident in the annual average. The cloud ceiling, or distance from the base of the clouds to the ground, can also be modified by human activities. Human activities produce high concentrations of nuclei close to the surface of the Earth. These nuclei plus water vapor permit the formation of clouds at lower levels of the atmosphere. Hence, human activities can lead to a lowering of the cloud ceiling. The number of hours per year with cloud ceiling lower than 5000 feet at the Missoula County Airport for the period 1951 to 1964 is shown in figure 3.30. During the period from 1951 to 1957 there was an average of 1804 hours per year with cloud ceiling less than 5000 feet. From 1958 to 1964 the average the average was 1916 hours per year. Cumulative cloud ceiling summaries

Figure 3.29

Average Sky Cover Sunrise to Sunset at the Missoula County Airport, 1951 - 1971.

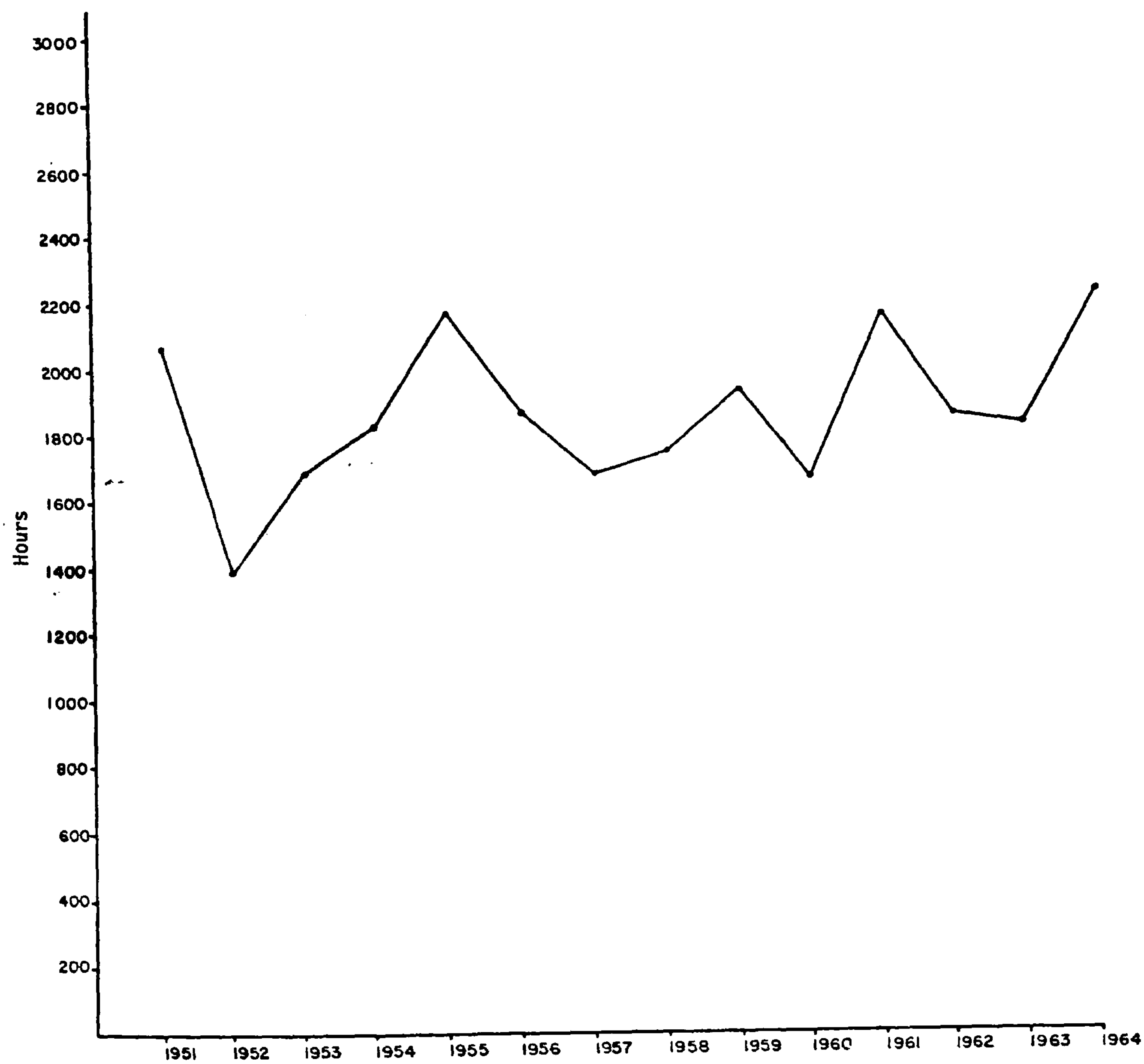

Figure 3.30

Number of Hours per Year with Cloud Ceiling Less Than 5000 Feet at the Missoula County Airport.

have not been published in the monthly local climatological data summary since 1964. The number of days per year with cloud ceiling less than 6000 feet during the entire twenty-four hour period is shown in figure 3.31 for 1961 to 1971. An increase in the number of days with cloud ceiling less than 6000 feet since 1961 is readily apparent. Data prior to 1961 is not available in the monthly local climatological data summary.

Particulate matter can have a major effect on incoming solar radiation. Numerous studies have shown that solar radiation is reduced dramatically by suspended particulate matter. Landsberg concluded that a city will receive about 20 percent less direct solar radiation than the surrounding countryside on an annual average.[52] Incoming solar radiation is reduced most in high latitude cities in the Winter. Since the sun angle is low at this time the path of light through the particulate is longer and hence the attenuation of the radiation is increased.

There are no measurements of incoming solar radiation made at Missoula, Montana. This is unfortunate since time series solar radiation measurements could give a good indication of the influence of human activities. The annual average percent possible sunshine for Missoula is shown in figure 3.32. Percent of possible sunshine is a measure of the length of time the sun is shining compared to the theoretical maximum. It is not a measure of solar energy. There is no apparent trend in percent possible sunshine in the Missoula Valley.

Urbanization can also modify wind speed and wind direction. Wind speeds in urban areas are less than rural locations and winds tend to converge toward urban areas. The two factors mainly responsible for this situation are the urban heat island effect and the turbulence and friction

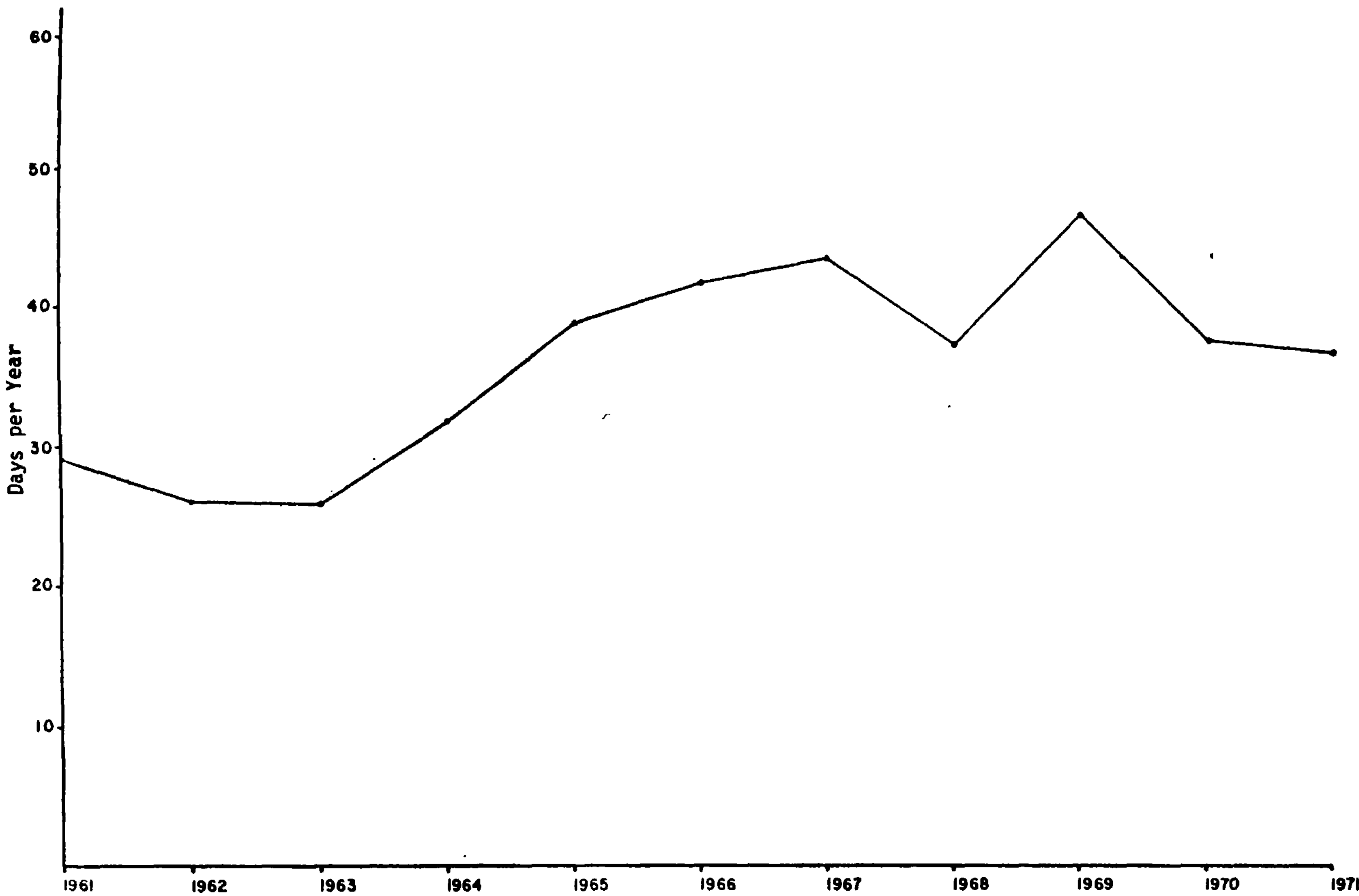

Figure 3.31

Number of Days per Year with Cloud Ceiling Less Than 6000 Feet at the Missoula County Airport.

Figure 3.32

Annual Average Percent of Possible Sunshine at the Missoula County Airport, 1951 - 1971.

created by buildings. There is no comparison data available in Missoula for wind speed and wind direction. The annual average wind speed recorded at the Missoula County Airport is shown in figure 3.33. The prevailing monthly wind direction from 1964 to 1971 is given in figure 3.34. Both wind speed and wind direction are important in determining pollutant concentrations in the Missoula Valley and will be considered further in Chapter Four.

In this chapter we have demonstrated the modification of several climatic variables which may be associated with human activity. It is easy to assume that human activity is responsible for climatic modification but it is much more difficult to unequivocally prove that fact. The behavior over time of a specific climatic variable is influenced by so many factors that it is often difficult to separate the various variables without detailed statistical analysis.

We have generally relied on a twenty year climatic record. The significance of a twenty year climatic record is certainly an open question when one considers the variable nature of climate in geologic time. We have compared several Missoula climatic variables with stations that were "climatically similar" In actuality it is very difficult to find stations which are "climatically similar" and comparisons are sometimes of questionable validity. We have also relied on existing data from the United States Weather Service for all our calculations. To unequivocally document various climatic effects such as the "heat island" effect would require a detailed grid of meteorological instrumentation and considerable experimental design. Also, many climatic effects caused by human activities are noticable only on a "micro" scale and are not visible in the climatic

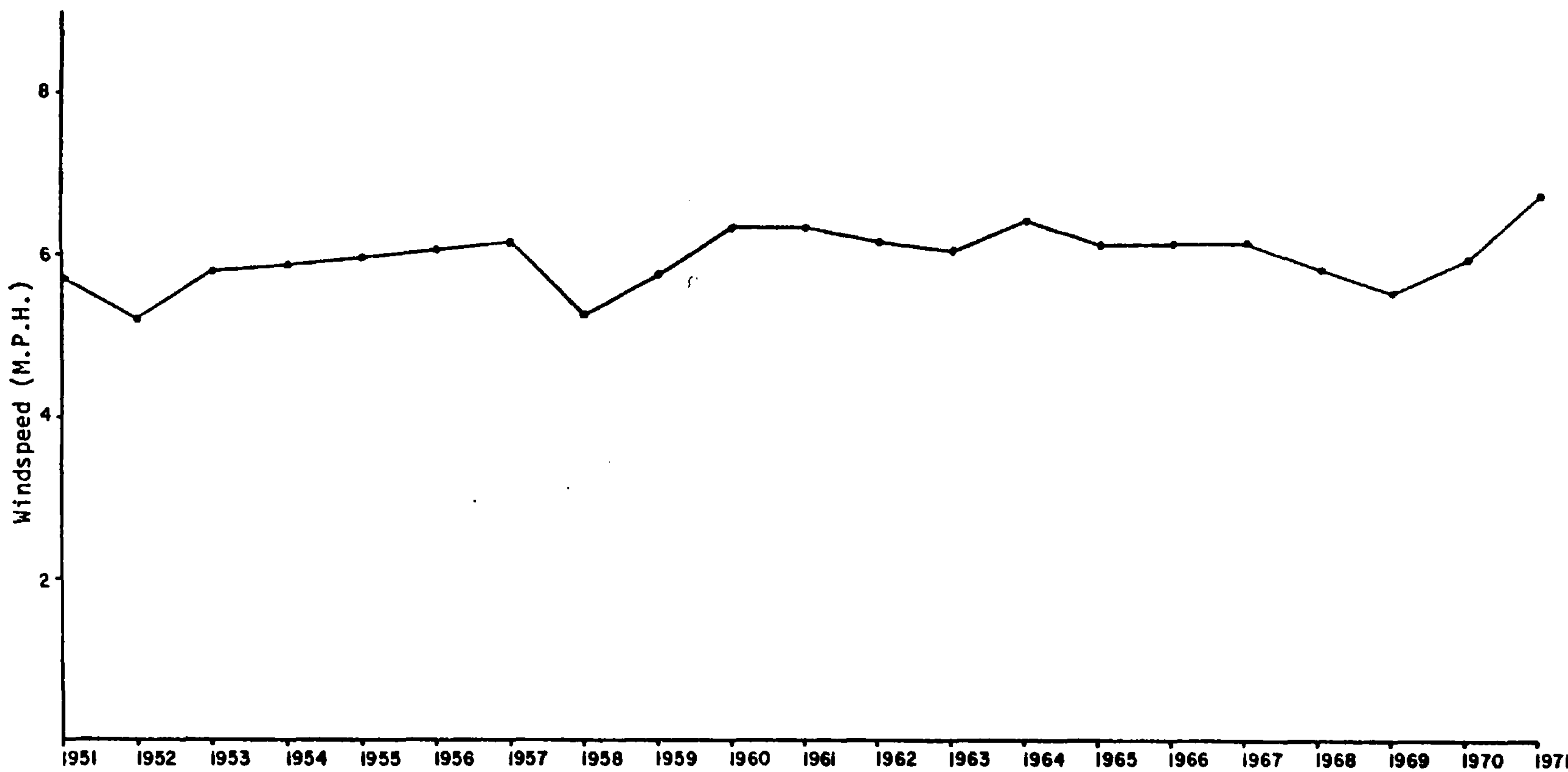

Figure 3.33

Annual Average Wind Speed at the Missoula County Airprot, 1951 - 1971.

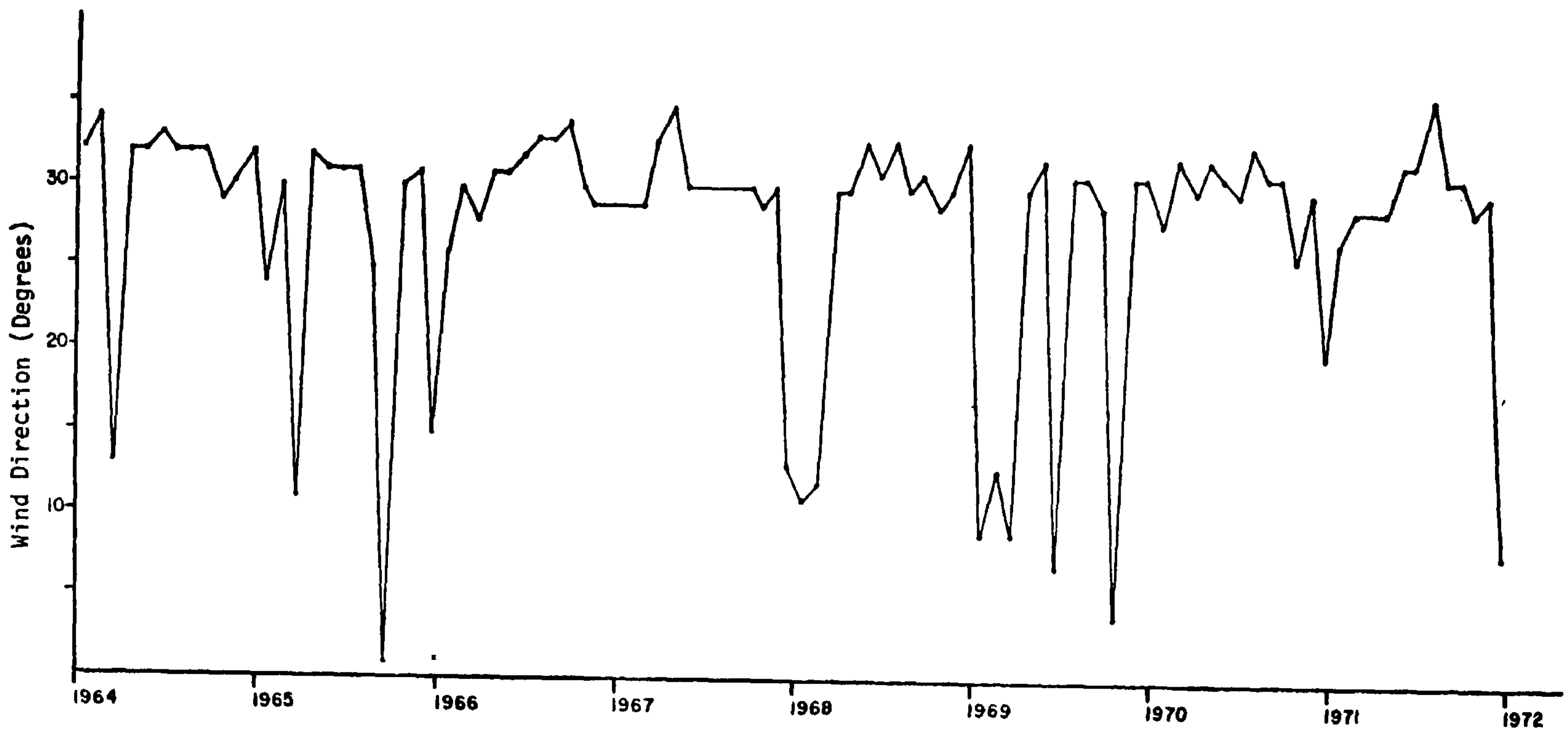

Figure 3.34

Prevailing Wind Direction in Tens of Degrees from True North, 1964 - 1971 -- Missoula County Airport.

history of a single station location.

In this study we have attempted to gather and summarize the existing climatic information for the Missoula Valley. We have plotted this time series data to determine the recent climatic history of the Missoula Valley. We believe that human activities are associated with the recent climatic fluctuations in the Missoula area. To prove a definite cause and effect relationship between human activities and climatic variation in the Missoula Region would require far more sophisticated statistical analysis and detailed original experimentation.

Chapter 4

SMOKE AND FOG

In Chapter Three we discussed the effects of human activities on various climatic parameters. The United States Weather Bureau at the Missoula County Airport also records hourly and three hourly observations of weather conditions. One of the categories of weather conditions is smoke and/or haze. Smoke at the Missoula Airport is entirely due to human activity in the Valley with the minor exception of smoke from natural forest fires in the summer. Smoke observations have been published in the local climatological data monthly summary for Missoula in some form since July 1956. Figure 4.1 shows the number of hours per year with smoke and/or haze recorded at the Missoula Airport from 1957 to 1964. Cumulative hourly totals were not published after 1964. Approximately sixty hours of smoke and haze were recorded in 1957 In 1962 over 1300 hours of smoke and haze were recorded. This increase can certainly be described as dramatic. The rise parallels the industrialization of the Missoula Valley and the increase in smoke must be considered one of the effects of industrialization. The monthly number of hours with smoke and/or haze is shown in figure 4.2. The number of hours of smoke peak in the winter months with minimal smoke during the summer. Inversion frequency and duration similarly peak during the Winter. The lack of smoke observations during the summer months also indicates that the smoke from forest fires is not a major contributor to

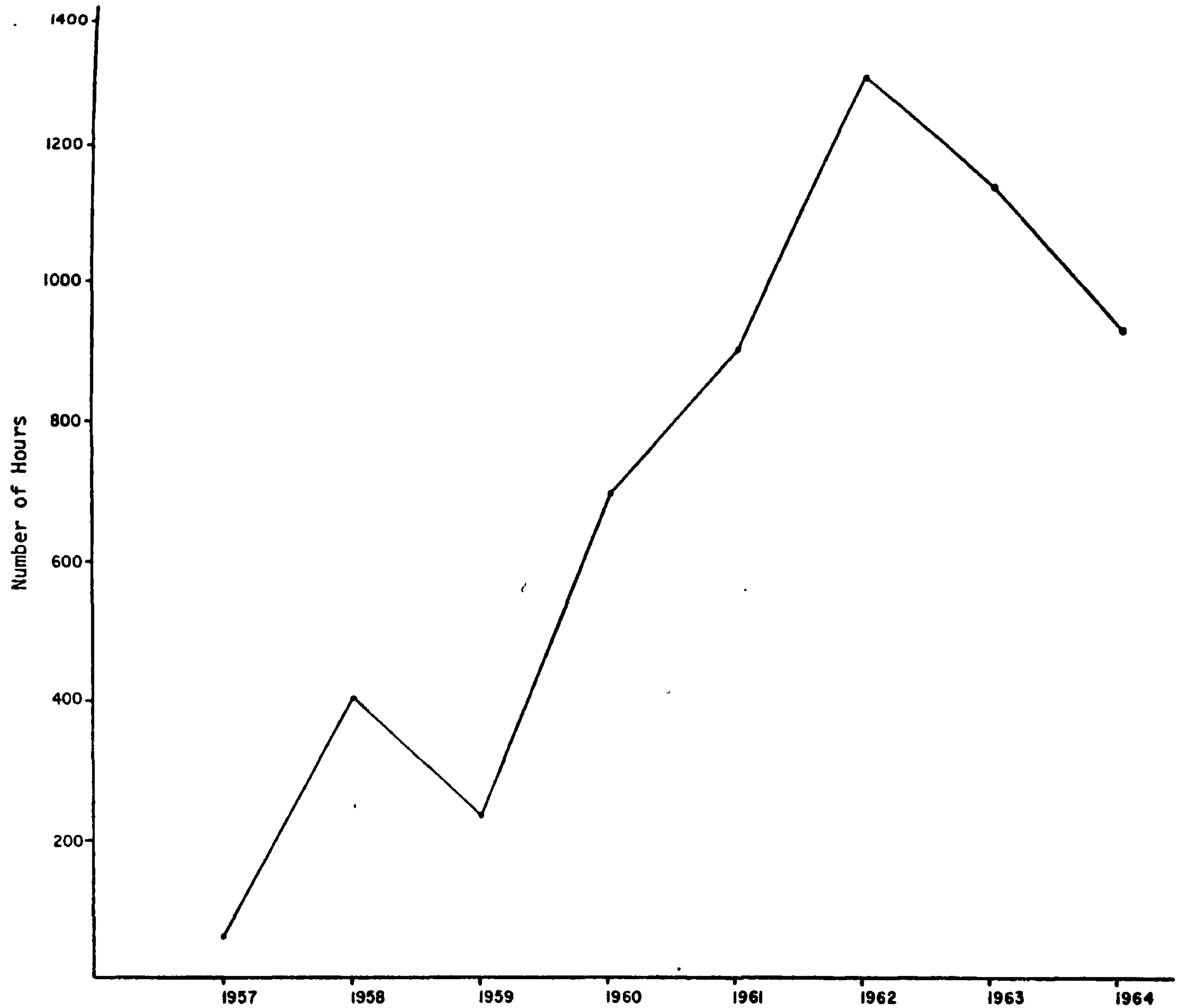

Figure 4.1

Number of Hours per Year of Smoke and Haze Recorded at the U.S. Weather Bureau -- Missoula County Airport.

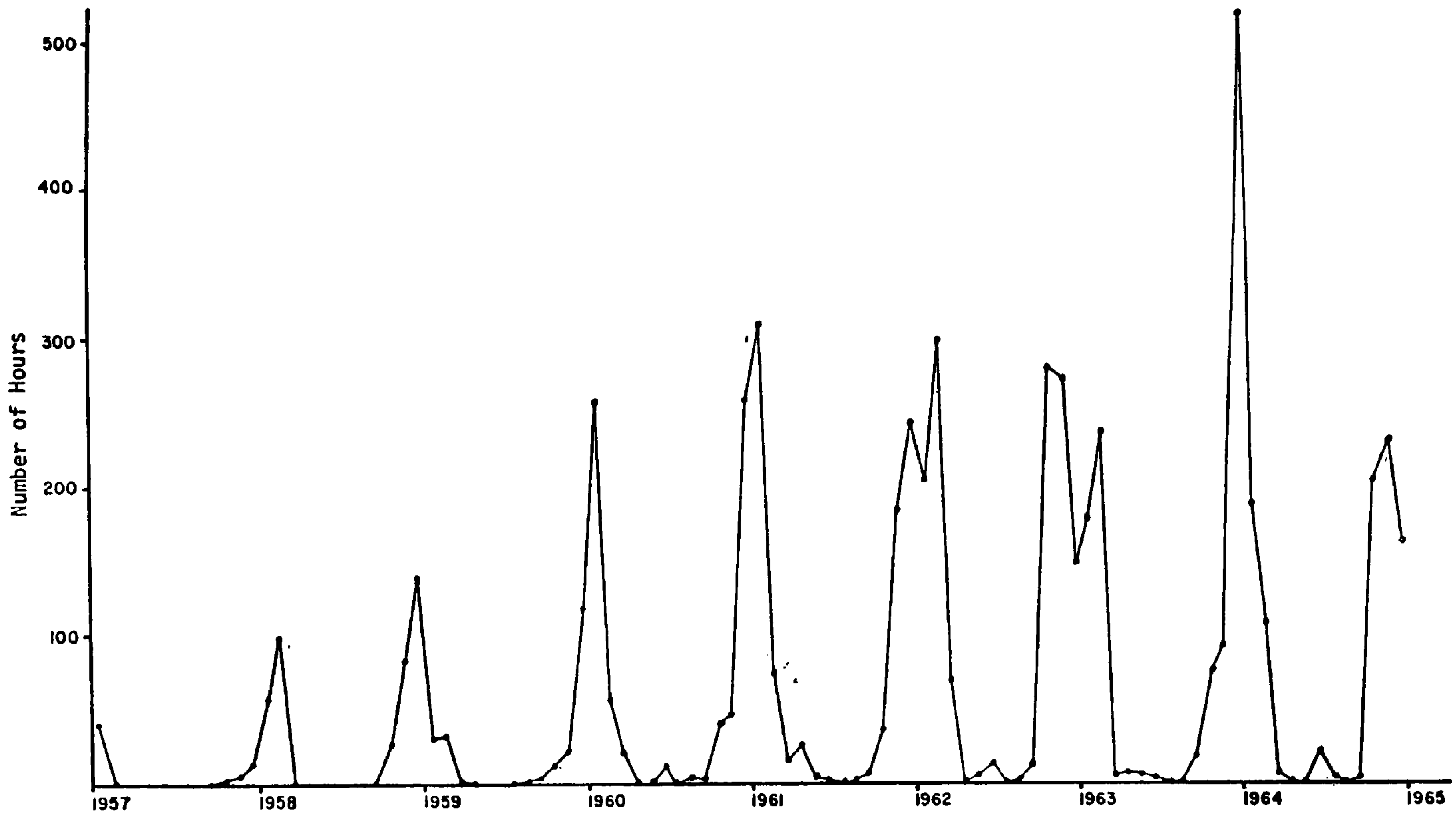

Figure 4.2

Number of Hours per Month with Smoke and Haze Recorded at the U.S. Weather Bureau -- Missoula County Airport.

the total. Smoke from man caused slash burning may add to Fall totals however. The number of days with smoke and haze is shown in figure 4.3 for the period from 1961 to 1971. Again daily totals are not published prior to 1961. The decline in smoke and haze days since 1969 parallels the visibility and fog data and is probably influenced by the decrease in inversion index.

In an attempt to determine the meteorological conditions associated with smoke and haze at the Missoula County Airport the observations of smoke and haze from September 1969 to December 1971 have been carefully analyzed. For comparison the observations of fog during the same time period were also studied. A total of 330 three hour observations of smoke and/or haze were studied along with 419 fog observations. A total of 12.1 percent of the days between September 1969 and December 1971 had smoke and/or haze recorded sometime during the day. Heavy fog, ground fog, or ice fog was observed sometime during 16.8 percent of those days. Smoke and fog occurred together on 8.2 percent of the days.

The relation between smoke and/or haze observations at the airport and the particulate levels recorded at the Missoula County Courthouse is interesting. On days when smoke and/or haze was recorded at the airport the twenty-four hour average particulate level at the courthouse was 146 ug/M^3, almost twice the federal and state annual average standard. The average for days with fog was 119 ug/M^3 and the average for all days from September 1969 to December 1971 was 114 ug/M^3 at the courthouse. The particulate average on smoke days is almost 28 percent higher than the average for all days and would be even higher if smoke days were compared to days without smoke. Several conclusions may be drawn from these

Figure 4.3

Number of Days per Year with Smoke and Haze Recorded at the U.S. Weather Bureau -- Missoula County Airport.

observations. First we can conclude that the meteorological conditions responsible for smoke and haze are conducive to atmospheric particulate loading. Secondly we can assume that observations of smoke at the airport are indicative of elevated particulate levels throughout the Valley since the courthouse and the airport are over six miles apart. Finally we can assume that the presence of fog is not an indicator of elevated particulate levels.

The first meteorological variable studied in association with smoke and fog was wind. Both wind speed and wind direction could be significant factors effecting the observation of smoke at the airport. The average wind speed during smoke observations was 2.4 miles per hour The average wind speed for fog observations was 2.6 miles per hour As a comparison the annual average wind speed at the airport in 1970 was 6.0 miles per hour and in 1971 was 6.8 miles per hour. These low wind speeds are generally associated with strong inversion conditions as was demonstrated in Chapter Three. The windrose for smoke and fog observations are shown in figures 4.4 and 4.5. Figure 4.6 gives the percentage frequency for smoke and fog observation in the various quadrants. In figure 4.7 the coordinates were rotated to confirm more to the topography of the Valley. It is interesting to note that the percentage frequency of wind direction for smoke observations and fog observations is almost identical. In both cases over 60 percent of the observations of smoke and fog occurred with wind direction either calm or from the northwest. Similarly over 60 percent of both the smoke and fog observations occurred when the wind was calm or up the Clark Fork Valley. From September 1969 to December 1971 the monthly prevailing wind direction was from the northwest in nearly

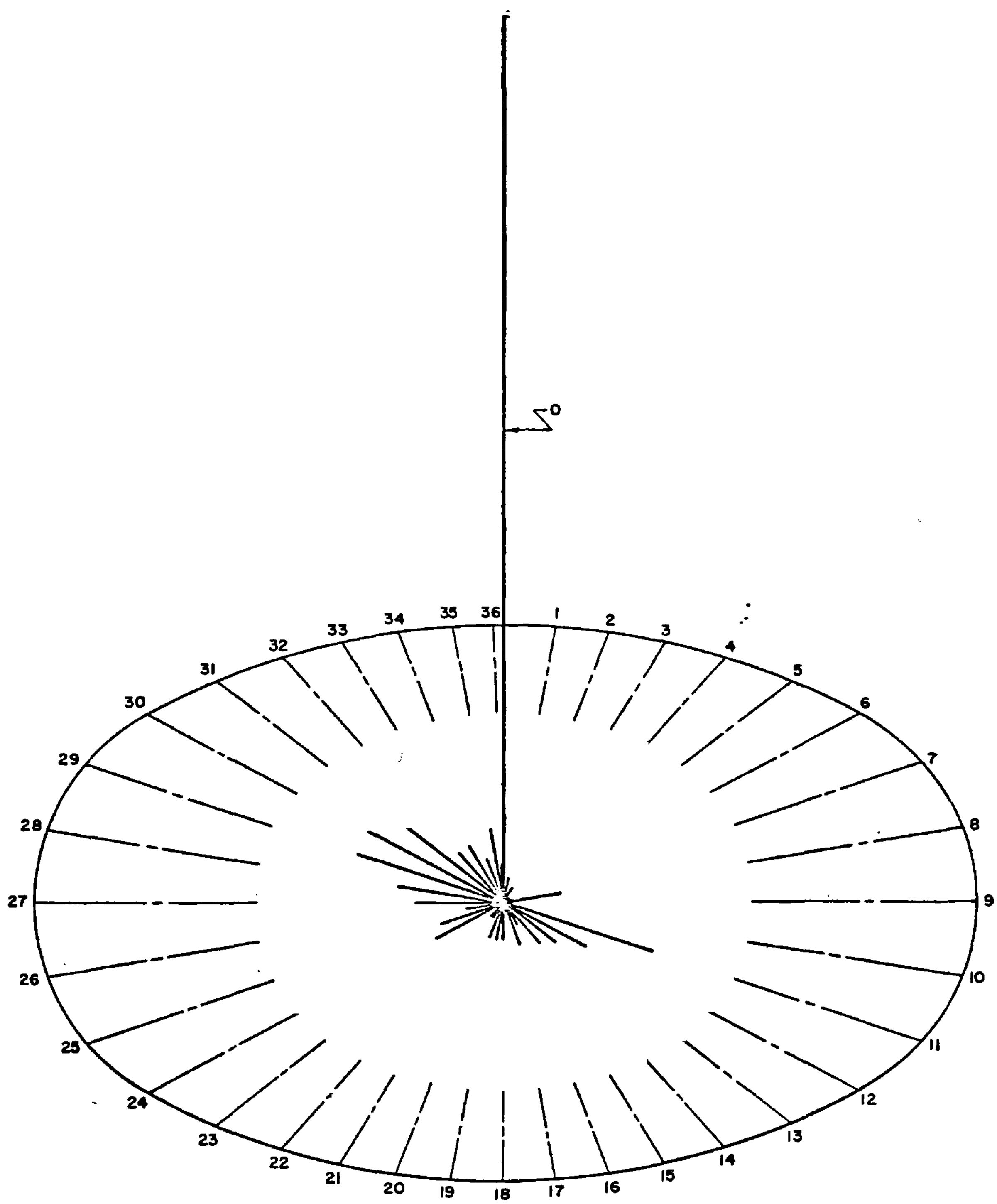

Figure 4.4

Windrose for Smoke Observations, Missoula County Airport, Sep. 1969 - Dec. 1971.

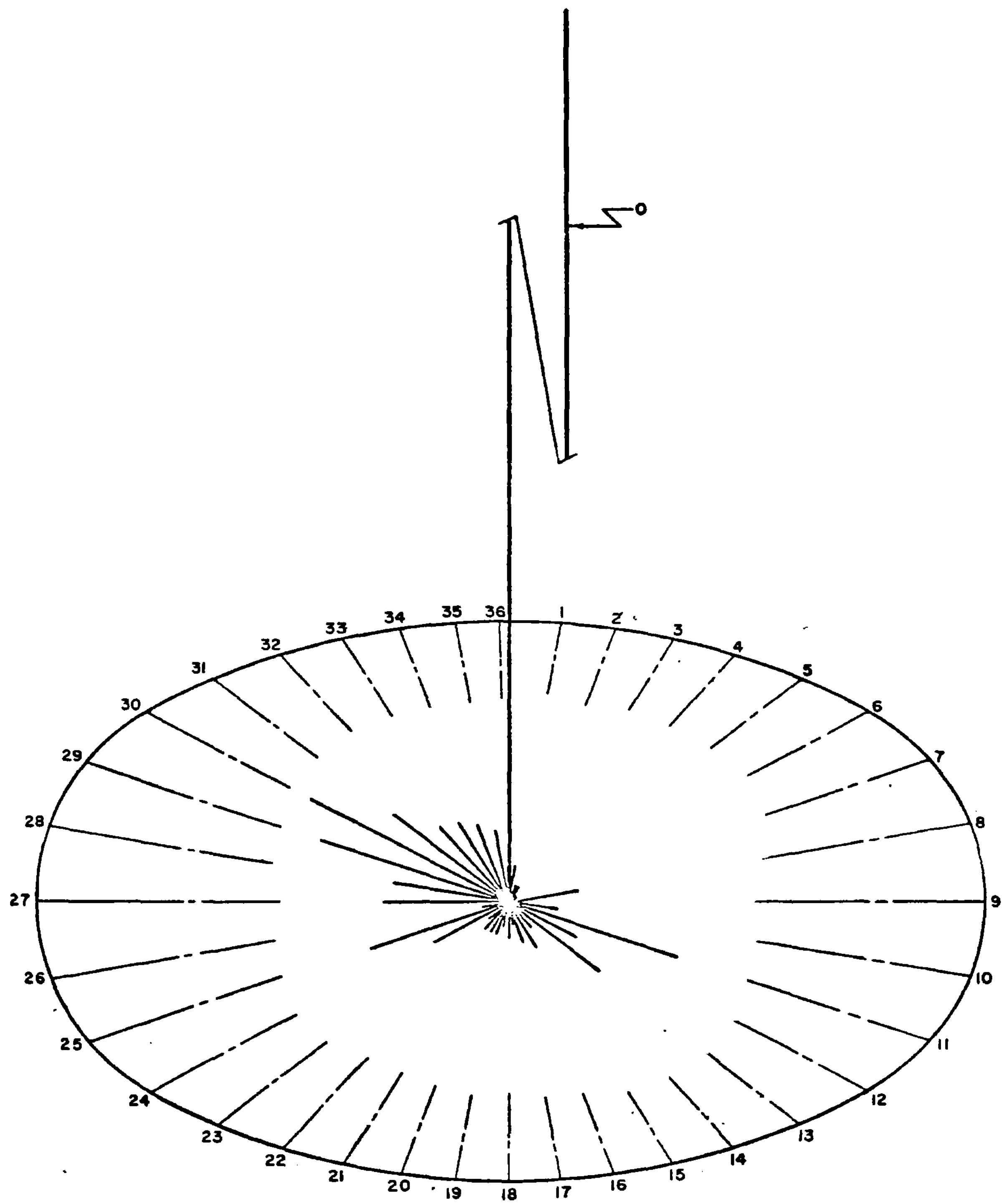

Figure 4.5

Windrose for Fog Observations, Missoula County Airport, Sep. 1969 - Dec. 1971.

QUADRANT	PERCENT OF ALL OBSERVATIONS SMOKE	PERCENT OF ALL OBSERVATIONS FOG
Calm (0)	29.7	30.7
1- 9	7.0	6.7
10-18	19.1	17.7
19-27	15.2	16.3
28-36	29.1	28.5

Figure 4.6

Percentage Frequency of Smoke and Fog Observations in Various Quadrants.

QUADRANT	PERCENT OF ALL OBSERVATIONS SMOKE	PERCENT OF ALL OBSERVATIONS FOG
Calm	29.7	30.7
33- 5	12.1	12.0
6-14	16.1	15.6
15-23	12.1	10.8
24-32	30.0	30.9

Figure 4.7

Percentage Frequency of Smoke and Fog Observations in Various Quadrants (Rotated Coordinate System).

80 percent of the months. It is unfortunate that the industrial development in the Missoula Valley also follows the valley west and northwest of the city.

The relative humidity associated with smoke and fog observations was also determined. The relative humidity occurring with smoke observations at the airport averaged 91 percent. The relative humidity for fog observations was 96 percent. One would expect high relative humidity with fog, however the 91 percent relative humidity for smoke observations seems unusual. The high relative humidity for smoke observations may perhaps be explained by the fact that most of the smoke observations occurred in the Winter when high relative humidity is a natural occurrence. The "normal" relative humidity at the airport during November, December, January. and February is over 80 percent with nighttime readings often averaging over 90 percent. In almost 34 percent of the smoke observations the associated relative humidity was less than 90 percent while 13 percent of the fog observations had relative humidity readings less than 90 percent. The relative humidity at which condensation and fog can occur depends on the size, type, and number of nuclei present in the atmosphere. Large, abundant, hygroscopic nuclei inhance condensation. One could expect that the observance of fog at relative humidities below saturation is due to atmospheric particulate matter, particularly since smoke observations are also associated with high relative humidity.

Inversion conditions are also associated with smoke and fog observations at the Missoula Airport. Inversion conditions were reported on 93 percent of the days with smoke observations and on 79 percent of the days with fog observations. The average 1200 M difference in temperature between T.V. Mountain and the Missoula Airport on days with smoke observations was 2.2^{o}F and on days with fog observations was 4.8^{o}F. Inversion conditions exist when this difference in temperature is less than 12.6^{o}F. The relationship between fog and inversion conditions was expected and indeed inversion conditions greatly inhance the formation of ground fog. One would also expect inversions to be associated with smoke observations, however, the observed relation was certainly dramatic since inversion conditions were even stronger for smoke days than for fog days. The existence of an inversion seems to be a prerequisite for the observation of smoke at the airport and temperature inversion may be the controlling factor in smoke accumulation. We must emphasize, however, that temperature inversions do not cause the observation of smoke at the airport. Human activity creates the smoke which then may accumulate under inversion conditions. If there were no smoke it could not accumulate.

Chapter 5

POLLUTION PREDICTION

In this chapter the meteorological conditions associated with particulate air pollution will be discussed in detail. For the purposes of this chapter we will assume that the particulate load in the Missoula Valley is constant and that meteorological conditions are responsible for the variation in particulate levels. Detailed particulate records are available from the courthouse sampling location from September 1969 to the present. For this study we considered the data through December 1971. We considered the following meteorological variables in the study: wind speed, temperature inversion, departure from normal temperature, precipitation, barometric pressure, percent of possible sunshine, cloud ceiling, and relative humidity. All meteorological data was obtained from the monthly local climatological summary for Missoula, Montana.

The twelve month period from July 1970 to June 1971 was studied extensively. From this study we were able to determine a number of meteorological conditions which seemed to be associated with elevated particulate levels. We consider these conditions to be pollution prediction categories. Figure 5.1 shows an analysis of the meteorological conditions (pollution prediction categories) associated with various particulate levels with a comparison to the averages for all days during the period. We observe that below average wind speed, temperature inversion, above

VARIABLE	ALL DAYS	DAYS PARTIC-ULATE > 135	DAYS PARTIC-ULATE < 60
% days with wind speed below average for month	55.3	76.5	45.6
% days with inversion during the day	55.6	76.5	41.1
% days with above monthly average departure from normal temperature	53.2	63.2	44.4
% days with zero or trace rainfall	60.8	93.5	27.9
% days with barometric pressure above average for month	46.6	60.5	27.9
% days with % possible sunshine above monthly average	51.2	83.0	21.5
% days with unlimited ceiling at 1100 M	43.0	67.1	16.5
% days with relative humidity below average for month at 1100 M	55.8	73.7	39.8
% days with 6 or more of the above categories present	35.1	65.8	2.5

Figure 5.1

Pollution Prediction Variables, July 1970 - June 1971.

average departure from normal temperature, zero rainfall, above average barometric pressure, above average percent possible sunshine, unlimited cloud ceiling, and below average relative humidity are all associated with elevated particulate levels. Six of the above categories were present on 65 percent of the days with particulate levels greater than 135 ug/M^3 while six or more categories were present on only 2.5 percent of the days with particulate levels less than 60 ug/M^3. Figure 5.2 is a summary of the actual average value of the meteorological variables associated with the particulate levels. These values simply reinforce the conclusions from Figure 5.1. Figure 5.3 gives the percentage deviation from the all days average for the various pollution prediction variables. Similarly figure 5.4 shows the percentage deviation from the all days average for the various meteorological averages. The pollution prediction categories and average meteorological conditions associated with particulate levels greater than 260 ug/M^3 are shown in figures 5.5 and 5.6. 260 ug/M^3 is the federal primary twenty-four hour average particulate standard and levels in excess may be a hazard to human health. The trends displayed in the earlier data are even more pronounced on days with particulate greater than 260 ug/M^3 Figure 5.7 gives the percentage composition of the pollution prediction categories for various particulate levels. Figure 5.7 indicates that the number of pollution prediction categories present increases substantially with increased particulate levels.

The data presented in figure 5.1 to 5.7 gives an indication of the meteorological conditions associated with high atmospheric particulate levels. Low wind speed, temperature inversion, zero rainfall, and high barometric pressure seem to be most associated with high particulate levels.

VARIABLE	ALL DAYS	DAYS PARTICULATE > 135	DAYS PARTICULATE < 60
Average wind speed (mph)	6.4	5.3	7.0
Average departure from normal temperature (^{O}F)	+1.5	+3.5	+1.0
Precipitation -- daily average (inches)	.037	.0039	.074
Average barometric pressure (inches of Mercury)	26.70	26.78	26.59
Average percent possible sunshine	56	75	32
Average relative humidity 1100 M (%)	63	56	73

Figure 5.2

Average Meteorological Conditions Associated with Particulate Levels -- Missoula, Montana.

Generally the number of pollution prediction categories present increase as the particulate level increases. A stable high pressure system seems to be most conducive to particulate accumulation. Particulate levels increase steadily as the high pressure system remains over the Missoula Valley.

In an attempt to more thouroughly document the relationship between meteorological variables and atmospheric particulate levels the statistical correlation between particulate levels and certain meteorological variables was determined. The linear least squares slope, Y intercept, correlation coefficient and standard deviation were determined for the daily particulate level versus several meteorological variables. The

VARIABLE	PERCENT DEVIATION FROM ALL DAYS AVERAGE DAYS PARTICULATE > 135	PERCENT DEVIATION FROM ALL DAYS AVERAGE DAYS PARTICULATE < 60
% days with wind speed below average for month	39.4	-17.5
% days with inversion during the day	37.6	-26.1
% days with above monthly average departure from normal temperature	18.8	-16.7
% days with zero or trace rainfall	53.0	-53.3
% days with barometric pressure above average for month	29.8	-40.1
% days with % possible sunshine above monthly average	62.2	-58.1
% days with unlimited cloud ceiling at 1100 M	56.0	-61.6
% days with relative humidity below average for month 1100 M	32.1	-28.7
% days with 6 or more of the above categories present	87.5	-93.5

Figure 5.3

Pollution Prediction Variables -- Deviation From All Days Average
July 1970 - June 1971.

VARIABLE	PERCENT DEVIATION FROM ALL DAYS AVERAGE DAYS PARTICULATE >135	PERCENT DEVIATION FROM ALL DAYS AVERAGE DAYS PARTICULATE <60
Average wind speed	-17.2	9.4
Average departure from normal temperature	133	-33
Precipitation -- daily average	-89.5	100
Average barometric pressure	.29	-.41
Average percent possible sunshine	34	-43
Average relative humidity 1100 M	-11.1	15.9

Figure 5.4

Average Meteorological Conditions Associated with Particulate Levels -- Deviation From All Days Average -- July 1970 - June 1971, Missoula, Montana.

meteorological variables studied included the daily average wind speed, daily average barometric pressure, daily percent of possible sunshine, daily rainfall, daily departure from normal temperature, 1100 M relative humidity, and 1200 M difference in temperature between T.V Mountain and the airport. Output was obtained for each month from September 1969 to December 1971 for the courthouse particulate sampling location. Output was also obtained for the Fort Missoula and airport particulate sampling locations from February through December 1971. All of the calculations were performed on an IBM 1620 computer on the University of Montana campus.

The linear least squares calculation determines the best straight line through a series of points. The least squares slope and Y intercept

VARIABLE	DAYS PARTICULATE >260
% days with wind speed below average for month	87.5
% days with inversion during the day	87.5
% days with above monthly average departure from normal temperature	43.8
% days with zero or trace rainfall	93.9
% days with barometric pressure above average for month	75.0
% days with % possible sunshine above monthly average	75.0
% days with unlimited cloud ceiling at 1100 M	56.3
% days with relative humidity below average for month 1100 M	65.7
% days with 6 or more of the above categories present	62.4

Figure 5.5

Pollution Prediction Variables -- Days with Particulate Level Greater Than 260 ug/M^3 -- September 1969 - December 1971, Missoula, Montana.

VARIABLE	ALL DAYS	DAYS PARTICULATE $\geq$ 260 ug/M^3
Average wind speed	6.4	4.0
Average departure from normal temperature	1.5	2.1
Precipitation (daily average)	.037	.0031
Average barometric pressure	26.70	26.86
Average % possible sunshine	56	69
Average relative humidity	63	66

Figure 5.6

Average Meteorological Conditions Associated with Particulate Levels Greater Than 260 ug/M^3 -- September 1969 - December 1971, Missoula, Montana.

give the equation for that line. The correlation coefficient gives a measure of the "randomness" of the points about the least squares line. The correlation coefficient ranges in value from -1 to +1. A correlation coefficient of -1 indicates an inverse linear relationship while a correlation of +1 indicates a positive linear relationship. A correlation coefficient of zero indicates that there is no linear functional relationship between the plotted variables.

Figures 5.8 to 5.14 give the monthly correlation coefficient for particulate versus the various meteorological variables. These computer calculations reinforce the conclusions from the pollution prediction calculations. We find that wind speed, rainfall, and temperature inversion are inversely correlated with particulate levels while barometric pressure

Days with Particulate Less Than 60 ug/M^3 -- 197 Days

% Days with 0 Pollution Prediction Categories Present	=	10.2
1	=	15.7
2	=	22.8
3	=	25.4
4	=	12.2
5	=	7.1
6	=	5.6
7	=	1.0
8	=	0.0

% Days with 4 or more categories present = 25.8
% Days with 6 or more categories present = 6.6

Days with Particulate Greater Than 135 ug/M^3 -- 198 Days

% Days with 0 Pollution Prediction Categories Present	=	0
1	=	1.5
2	=	5.0
3	=	11.6
4	=	16.7
5	=	13.1
6	=	21.8
7	=	18.7
8	=	11.6

% Days with 4 or more categories present = 81.9
% Days with 6 or more categories present = 52.1

Days with Particulate Greater Than 260 ug/M^3 -- 32 Days

% Days with 0 Pollution Prediction Categories Present	=	0
1	=	0
2	=	0
3	=	9.4
4	=	21.8
5	=	6.3
6	=	21.8
7	=	21.8
8	=	18.8

% Days with 4 or more categories present = 90.5
% Days with 6 or more categories present = 62.4

Figure 5.7

Pollution Prediction Categories -- September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	-.195		
OCT	-.614		
NOV	-.388		
DEC	-.186		
JAN 1970	-.450		
FEB	-.282		
MAR	-.414		
APR	.365		
MAY	-.0643		
JUN	-.400		
JUL	-.500		
AUG	-.151		
SEP	-.404		
OCT	-.652		
NOV	-.184		
DEC	-.438		
JAN 1971	-.310		
FEB	-.532	-.178	
MAR	-.242	-.391	-.0820
APR	-.0882	-.433	-.346
MAY	-.354	-.460	-.577
JUN	.0596	-.141	-.115
JUL	-.483	-.412	-.0397
AUG	-.147	-.473	-.328
SEP	-.193	-.460	-.274
OCT	-.197	-.419	-.318
NOV	-.124	-.358	-.192
DEC	-.448	-.496	-.368

Figure 5.8

Correlation Coefficient -- Wind Speed versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	.613		
OCT	.0310		
NOV	.486		
DEC	.170		
JAN 1970	.503		
FEB	.304		
MAR	.00232		
APR	.127		
MAY	.255		
JUN	.481		
JUL	.0670		
AUG	-.412		
SEP	.426		
OCT	.454		
NOV	.521		
DEC	.0852		
JAN 1971	.476		
FEB	.440	-.0634	
MAR	.511	.358	.279
APR	.282	.403	.597
MAY	-.0537	.160	.462
JUN	-.0906	.0833	.0801
JUL	-.344	.0972	.320
AUG	-.0824	.109	.225
SEP	.163	.261	.229
OCT	.231	.445	.602
NOV	.272	.0255	.0459
DEC	.365	.330	.292

Figure 5.9

Correlation Coefficient -- Barometric Pressure versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	-.503		
OCT	-.301		
NOV	-.068		
DEC	-.249		
JAN 1970	-.276		
FEB	-.304		
MAR	-.377		
APR	-.322		
MAY	-.340		
JUN	-.422		
JUL	-.617		
AUG	-.229		
SEP	-.305		
OCT	-.397		
NOV	-.230		
DEC	-.148		
JAN 1971	-.163		
FEB	-.252	-.515	
MAR	-.343	-.0779	-.393
APR	-.477	-.371	-.555
MAY	-.327	-.229	-.427
JUN	-.226	-.288	-.271
JUL	-.234	-.325	-.290
AUG	-.232	-.464	-.245
SEP	-.295	-.312	-.278
OCT	.0899	-.171	-.019
NOV	-.511	-.272	-.392
DEC	-.274	-.268	-.248

Figure 5.10

Correlation Coefficient -- Rainfall versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	.220		
OCT	.538		
NOV	.144		
DEC	.274		
JAN 1970	.463		
FEB	.581		
MAR	.454		
APR	.302		
MAY	.664		
JUN	.771		
JUL	.714		
AUG	.00299		
SEP	.364		
OCT	.618		
NOV	.232		
DEC	.254		
JAN 1971	.266		
FEB	.331	.00600	
MAR	.617	.298	.321
APR	.501	.514	.655
MAY	.583	.609	.630
JUN	.517	.597	.467
JUL	-.212	.106	.176
AUG	.355	.687	.566
SEP	.588	.656	.567
OCT	.222	.588	.504
NOV	.363	.211	.327
DEC	-.0459	.210	.236

Figure 5.11

Correlation Coefficient -- Sunshine versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	.390		
OCT	.193		
NOV	-.358		
DEC	-.582		
JAN 1970	-.323		
FEB	-.311		
MAR	-.0997		
APR	.261		
MAY	.517		
JUN	.749		
JUL	.347		
AUG	.571		
SEP	.467		
OCT	.364		
NOV	.0614		
DEC	-.297		
JAN 1971	-.198		
FEB	-.144	.0916	
MAR	-.170	-.2045	-.248
APR	.537	.0637	.227
MAY	.671	.600	.376
JUN	.473	.323	-.120
JUL	.295	.288	.510
AUG	.235	.342	.153
SEP	.316	.178	.178
OCT	.383	.305	.445
NOV	-.148	.00733	.147
DEC	-.300	-.569	-.431

Figure 5.12

Correlation Coefficient -- Departure from Normal Temperature versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	-.532		
OCT	-.0932		
NOV	-.112		
DEC	.220		
JAN 1970	.294		
FEB	-.223		
MAR	-.0127		
APR	-.404		
MAY	-.698		
JUN	-.715		
JUL	-.510		
AUG	-.526		
SEP	-.218		
OCT	-.416		
NOV	-.128		
DEC	.164		
JAN 1971	.0112		
FEB	-.0184	-.0297	
MAR	-.298	.0794	-.123
APR	-.598	-.378	-.532
MAY	-.509	-.425	-.337
JUN	-.586	-.618	-.465
JUL	-.0368	-.150	-.263
AUG	-.472	-.558	-.485
SEP	-.391	-.309	-.476
OCT	-.317	-.161	-.459
NOV	-.410	-.339	-.491
DEC	.0264	.0842	.176

Figure 5.13

Correlation Coefficient -- Relative Humidity versus Particulate
September 1969 - December 1971, Missoula, Montana.

	COURTHOUSE	AIRPORT	FORT MISSOULA
SEP 1969	-.726		
OCT	-.682		
NOV	-.0877		
DEC	-.418		
JAN 1970	-.385		
FEB	-.282		
MAR	-.150		
APR	.165		
MAY	-.103		
JUN	-.161		
JUL	-.520		
AUG	-.315		
SEP	-.689		
OCT	-.730		
NOV	-.0271		
DEC	-.335		
JAN 1971	-.357		
FEB	-.378	-.00630	
MAR	-.249	-.661	
APR	-.186	-.274	
MAY	-.231	-.171	
JUN	-.0966	-.234	
JUL	-.352	-.0416	
AUG	-.318	-.363	
SEP	-.273	-.510	
OCT	-.204	-.559	
NOV	-.449	- 486	
DEC	-.220	-.158	

Figure 5.14

Correlation Coefficient -- Difference in Temperature Between T.V Mountain and Missoula County Airport 1200 M versus Particulate September 1969 - December 1971, Missoula, Montana.

and percent of possible sunshine are positively correlated with atmospheric particulate levels. Both relative humidity and departure from normal temperature exhibit interesting patterns. Relative humidity is inversely correlated with particulate levels during the summer months and positively correlated during the winter months. We noticed in Chapter Four that the observation of smoke at the airport was associated with high relative humidity levels and in Chapter Five we found that in general elevated particulate levels were associated with below average relative humidity. This apparent conflict may be resolved when we recall that the vast preponderance of smoke observations occurred during the winter months where particulate is positively correlated with relative humidity This relationship also explains why the pollution prediction percentage for relative humidity on days with particulate greater than 260 ug/M^3 drops when compared to days with particulate greater than 135 ug/M^3. Most of the days with particulate greater than 260 ug/M^3 also occur in the winter. Departure from normal temperature is positively correlated with particulate levels during the summer months and inversely correlated during the winter. Again this observation explains the drop in the pollution prediction percentage for departure from normal temperature on days with particulate greater than 260 ug/M^3.

There are obviously exceptions to the trends in particulate correlation we have discussed in this chapter. The correlation coefficients do not exhibit exact linear relationships for the various variables, however, truly linear behavior certainly could not be expected. The fact that any correlation at all exists is interesting since atmospheric particulate levels are certainly affected by many other variables besides weather conditions and the assumption that the particulate load in the valley is constant is quite drastic. The interaction among weather variables has not been considered although this factor is also important in determining atmospheric particulate levels.

The data included in this chapter could probably become the basis for a pollution prediction model based on meteorological conditions. Much more detailed analysis of the weather variables would be necessary, however some trends are apparent. Meteorological conditions are probably a controlling factor in the accumulation of atmospheric particulate matter in the Missoula Valley. From this analysis we have found that low wind speed, temperature inversion, zero rainfall, and high barometric pressure are most associated with elevated particulate levels. High barometric pressure, temperature inversion, and low wind speed indicate atmospheric stability and hence allow the accumulation of pollutants. Rainfall effects particulate levels in two ways. First particulate matter may be "washed" from the atmosphere by precipitation. Secondly and probably more important, precipitation is usually associated with atmospheric turbulence which disperses pollution accumulations. High percent possible sunshine, below average winter temperatures, above average summer temperatures, and below average summer relative humidity are all closely associated with high barometric pressure and are thus indirectly related to particulate levels. Elevated winter relative humidity does not seem to be associated to any degree with high barometric pressure. In general particulate air pollution levels increase as the number of pollution prediction variables increase. The increase in pollution prediction variables is usually associated with a stable high pressure system. In order to predict particulate levels accurately the percentage frequency of the simultaneous occurrence of various weather variables would have to be determined, however, the limited calculations presented here show that the prediction of particulate levels may be possible in the Missoula Valley. Certainly general pollution forcasts can be made on the basis of this data.

Chapter 6

SUMMARY AND CONCLUSIONS

This study was intended to be a comprehensive, detailed analysis of climatic modification in the Missoula Valley and the meteorological conditions associated with particulate air pollution. After over a year of research we feel that we have hardly begun to initiate the research necessary to thoroughly document climatic modification and develop a pollution prediction model We have been able to assemble most of the existing climatic information for the Missoula area, however, much more detailed statistical analysis is needed. Considerable experimentation would also be necessary to measure certain climatic variables for which we are presently lacking data, and to add more meteorological stations. A detailed grid of temperature recording stations would be necessary to document the "heat island" effect. Also a series of temperature recording stations running up Mount Sentinel behind the University of Montana would give valuable temperature inversion data. Relative humidity has probably increased in the Missoula Valley in recent years, however comparison data is lacking. A thorough study of relative humidity in the Missoula area might prove interesting. Perhaps the most interesting climatic data for Missoula which is currently lacking is solar insolation. The urban-rural solar insolation difference would be easy to document in a valley system such as the Missoula area.

We believe that the influence of human activity is present in the recent climatic record of the Missoula Valley. This influence is demonstrated in the "heat island" effect where the city is warmer than its surrounding environment,in increased fog, decreased visibility, lower cloud ceiling and increased relative humidity. The observation of smoke and/or haze at the Missoula County Airport has increased dramatically in the last fifteen years, paralleling the industrialization of the Missoula Valley. The influence of certain meteorological variables, particularly temperature inversion, on visibility, fog, and smoke observations is readily apparent.

Meteorological variables have a definite influence on the atmospheric particulate levels in the Missoula area. Low wind speed, temperature inversion, zero rainfall, and high barometric pressure are all associated with elevated particulate levels. A pollution prediction model based on meteorological conditions appears feasible from this preliminary analysis. In this study eight meteorological conditions were designated pollution prediction categories. The number of pollution prediction categories present increased with increasing particulate levels. In general the atmospheric particulate levels seemed most correlated with stable high pressure systems and atmospheric stagnation conditions in the Missoula Valley. While we are not yet able to predict atmospheric particulate levels with certainty we believe that enough data exists so that general particulate forecasting can be accomplished.

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RESPIRATORY ILLNESS IN THE MISSOULA VALLEY

UNIVERSITY OF MONTANA
STUDENT ENVIRONMENTAL RESEARCH CENTER

RESEARCH REPORT #4

John McBride, Christine Anderson

DECEMBER 1972

TABLE OF CONTENTS

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The principal workers in this study are listed on the cover, those students underlined received National Science Foundation stipend support.

Statistical data for this study were obtained from the Missoula County Clerk and Recorders Office and from the Medical Records Department at St. Patrick's Hospital. These data were transcribed by the students participating in the study. The University of Montana Student Environmental Research Center is responsible for the accuracy of this transcription.

INTRODUCTION

We report here the first preliminary results of the Missoula Valley air pollution - respiratory disease study conducted by the University of Montana Student Environmental Research Center. In this study we have attempted to determine the correlation between the incidence of respiratory illness in the Missoula Valley and various environmental parameters. Three sources of data were used to determine the incidence of respiratory illness in Missoula: death indices from the Missoula County Clerk and Recorders Office; admission records from St. Patrick's Hospital, the major hospital serving the community during the period of study; and actual physician's visits for respiratory illness. The analysis of the death indices covered the period from 1950 to 1971; St. Patrick's Hospital admissions were available from 1955 to the present; while the analysis of physicians visits for respiratory illness began in the spring of 1972.

In Chapter One of this report we detail and characterize the admission rates at St. Patrick's Hospital for various respiratory diseases. Some preliminary statistical analysis is also presented. Chapter Two considers the death rate for certain respiratory diseases in Missoula County. Finally, in Chapter Three we present a summary and conclusions based on our research to date.

The Student Environmental Research Center plans to publish a comprehensive monograph which will discuss in detail the health effects of air pollution, with particular emphasis on air pollution and respiratory illness in the Missoula Valley. More detailed statistical analysis of the hospital admissions and respiratory deaths will be published at that time, and additionally the results of the physicians visit study will be presented.

Chapter One

Respiratory Admissions to St. Patrick's Hospital

In this chapter we will consider the per capita, time series incidence of certain specific respiratory illnesses as evidenced by admissions to St. Patrick's Hospital. During the time of the study St. Patrick's Hospital was the major hospital in the Missoula area. Missoula County population was used to determine per capita incidence.[1] St. Patrick's Hospital does draw patients from outside Missoula County. During the period from 1967 through 1971 28.4 $\pm$ 0.8 percent of the admissions to St. Patrick's Hospital were not Missoula County residents. During the same time period 62.6 $\pm$ 1 percent of the admissions were from the city of Missoula. The percentage of non-Missoula County respiratory admissions is not known. It might be expected, however, that the admissions for acute respiratory illnesses are more representative of the Missoula County population base. In any case the per capita admissions for respiratory illnesses reported in this paper are probably higher than the actual Missoula County admission rate. The actual Missoula County Hospital Admission rate for respiratory illness must also reflect the admissions to the other hospitals in the community. The rates reported in this paper should be increased by the respiratory admission rates to the other hospitals. Since the admission rate to St. Patrick's hospital is so much higher than the other hospitals, this effect is assumed to be quite small. In our analysis of the per capita admission data, we have assumed that the out of county respiratory admissions and the respiratory admissions to the other hospitals in Missoula are constant with time and hence are not reflected in the time series statistics.

St. Patrick's Hospital records anonymous statistical information about each patient in addition to such personal charts and diagnostic material that may be required. This information includes each patient's age, sex, discharge date, and the International Statistical Disease Classification of the discharge diagnosis.[2] While, throughout our analysis we refer to hospital admission data,the statistical information actually recorded is the hospital discharge diagnosis. This information was compiled to provide age and sex specific, monthly and annual totals for the various respiratory illnesses. The data were then converted to admission rates per 100,000 population, a standard epidemiological technique. In this study the per capita admission rate for asthma, acute upper respiratory infection, acute and chronic bronchitis, emphysema, acute and chronic pharyngitis and nasopharyngitis, pneumonia, and acute and chronic sinusitis were determined.

The annual total admission rate to St. Patrick's Hospital for all the respiratory illnesses included in our study for the period 1956 to 1971 is shown in figure 1.1. We can observe that the total annual respiratory admission rate fluctuates widely. The average annual respiratory admission rate to St. Patrick's hospital is 1354 admissions per 100,000 population. The total admission rate for all illnesses is shown in figure 1.2. The annual admission rate for all causes has remained almost constant from 1956 through 1971. The annual percentage of respiratory admissions is shown in figure 1.3. The specific admission rates for the various respiratory illnesses are shown in figures 1.4-1.13.

A few general trends in the hospital admission rates are noticable. We observe a general decrease in the admission rate for asthma, acute pharyngitis and nasophayngitis, and acute sinusitis. The admission rates for chronic bronchitis, emphysema, and chronic sinusitis have increased substantially during the same time period. The general trend seems to be toward an increase in chronic respiratory illness and a decrease in acute respiratory admissions. There seems to be an increase in the percentage of patients admitted with respiratory illness during the period from 1956 to 1971, however,the annual fluctuation is wide.

The percentage of admissions by sex for the various respiratory illnesses is shown in figures 1.14-1.23. The most striking sexual differentiation is found with emphysema and acute upper respiratory infection. Seventy-three per cent of all emphysema admissions are male while 60 per cent of the acute upper respiratory infection admissions are female. It is particularly interesting that the sexual differentiation for emphysema is decreasing. In recent years the percentage of female emphysema admissions is greater than 30 per cent.

The percentage of hospital admissions in various age groups is shown in figures 1.24-1.33. Generally the highest percentage of admissions for acute respiratory illnesses are in the 0-4 age group. The older age groups are predominant in the chronic illnesses. No detailed analysis for time series trends in age differentiation have yet been undertaken; however,no trends are particularly obvious.

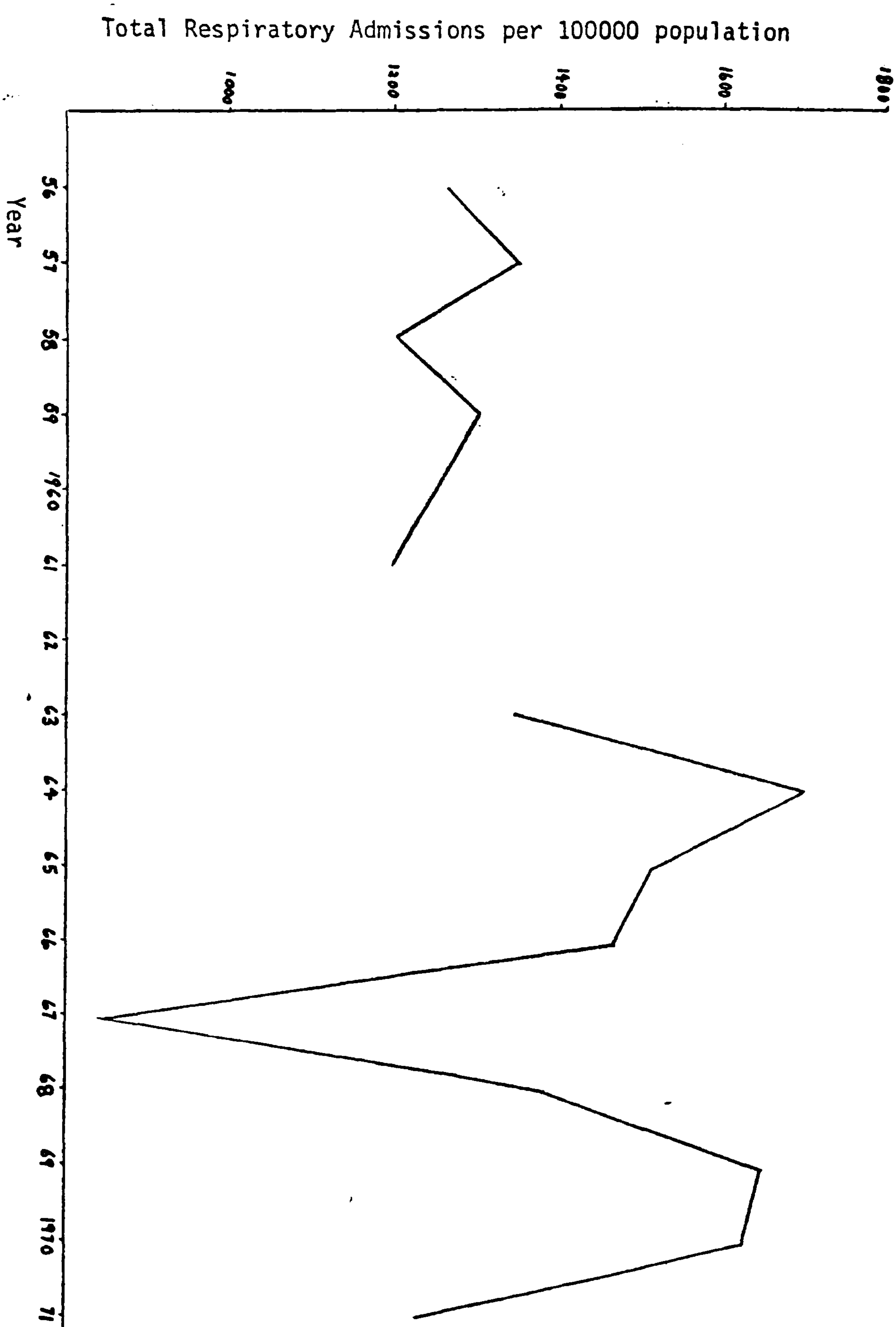


Figure 1.1
Total Respiratory Admissions to St. Patrick's Hospital 1956-1971

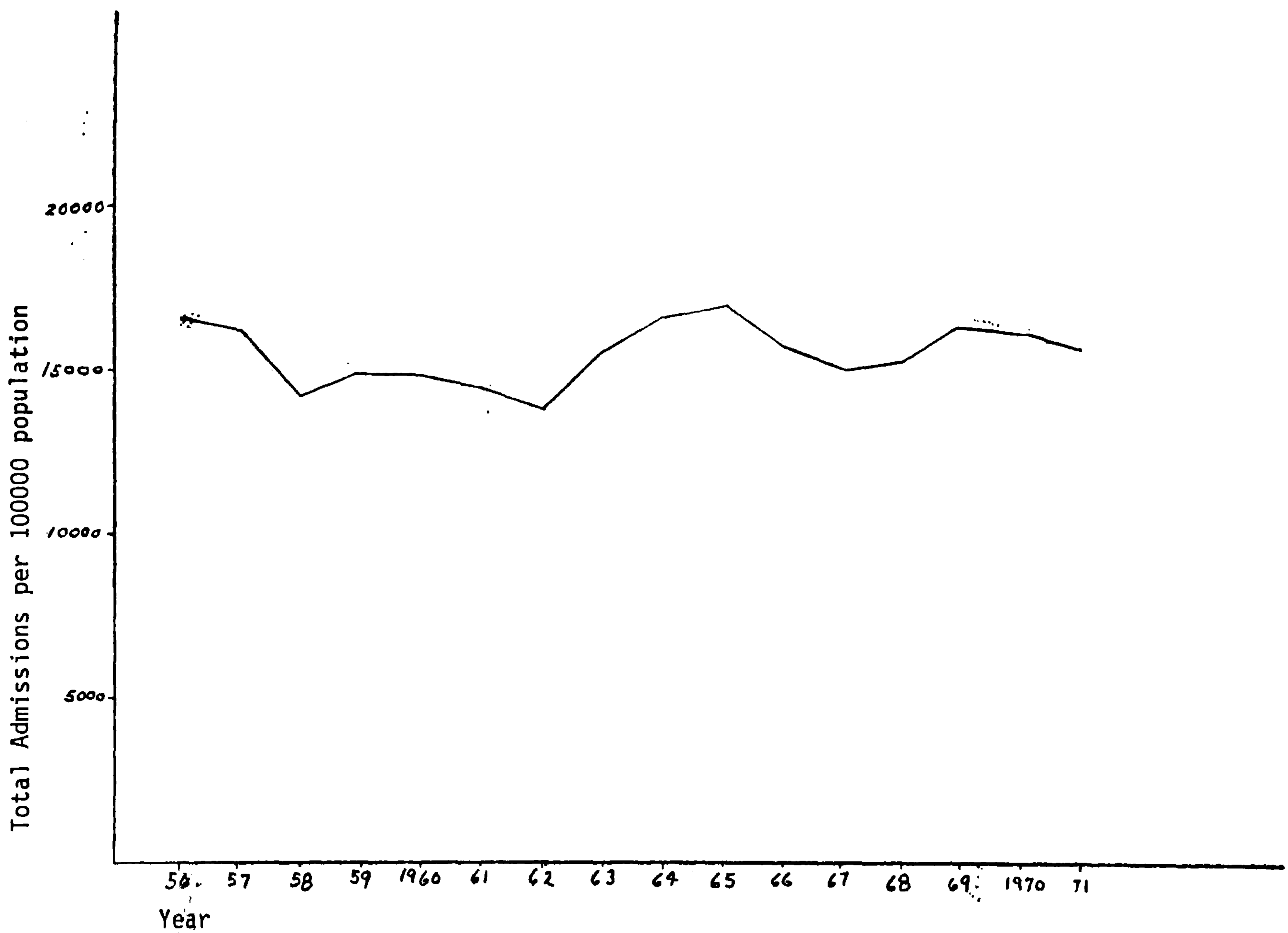


Figure 1.2

Total Admissions to St. Patrick's Hospital 1956-1971

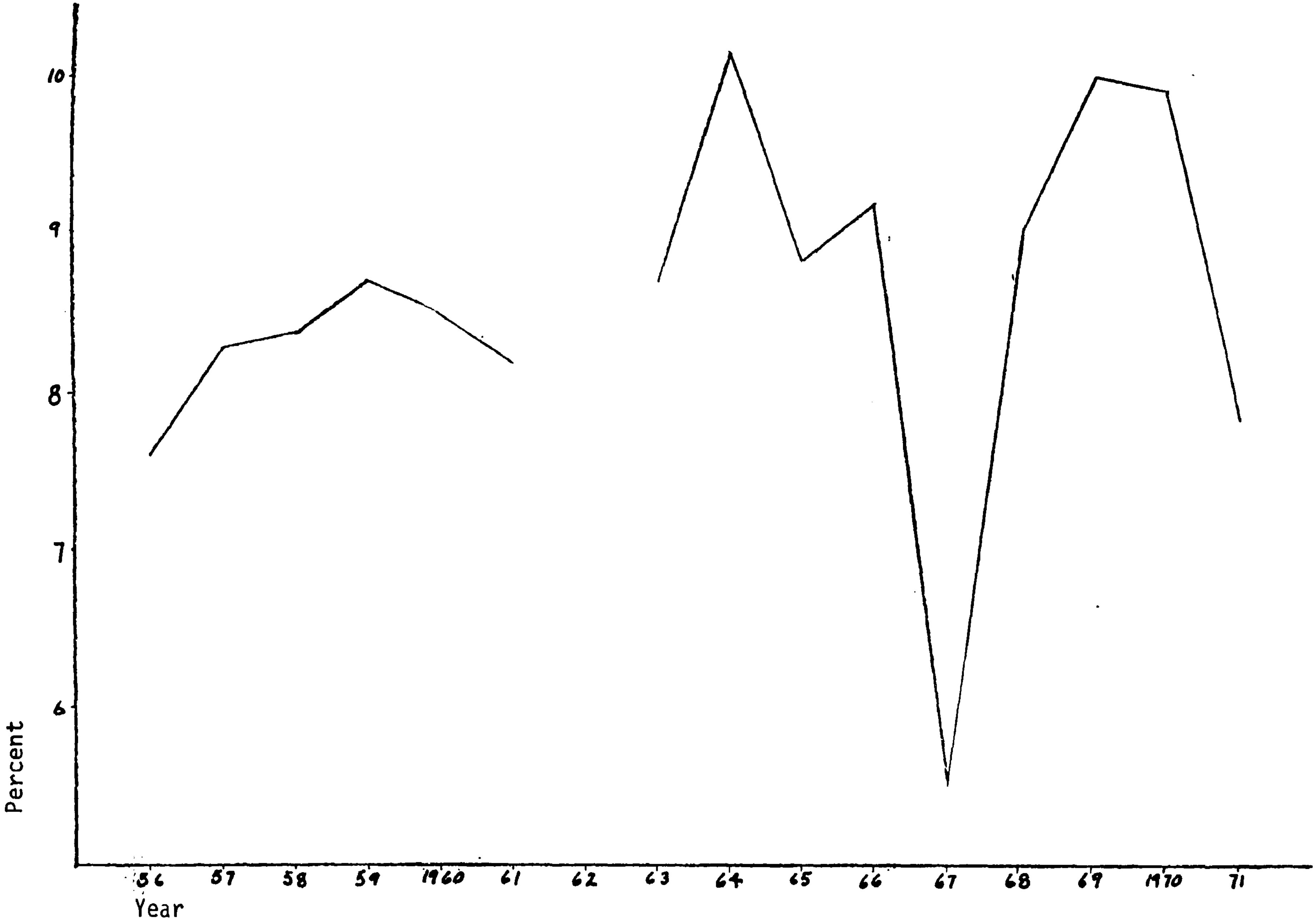


Figure 1.3

Percent of Total Hospital Admissions with Respiratory Complaint

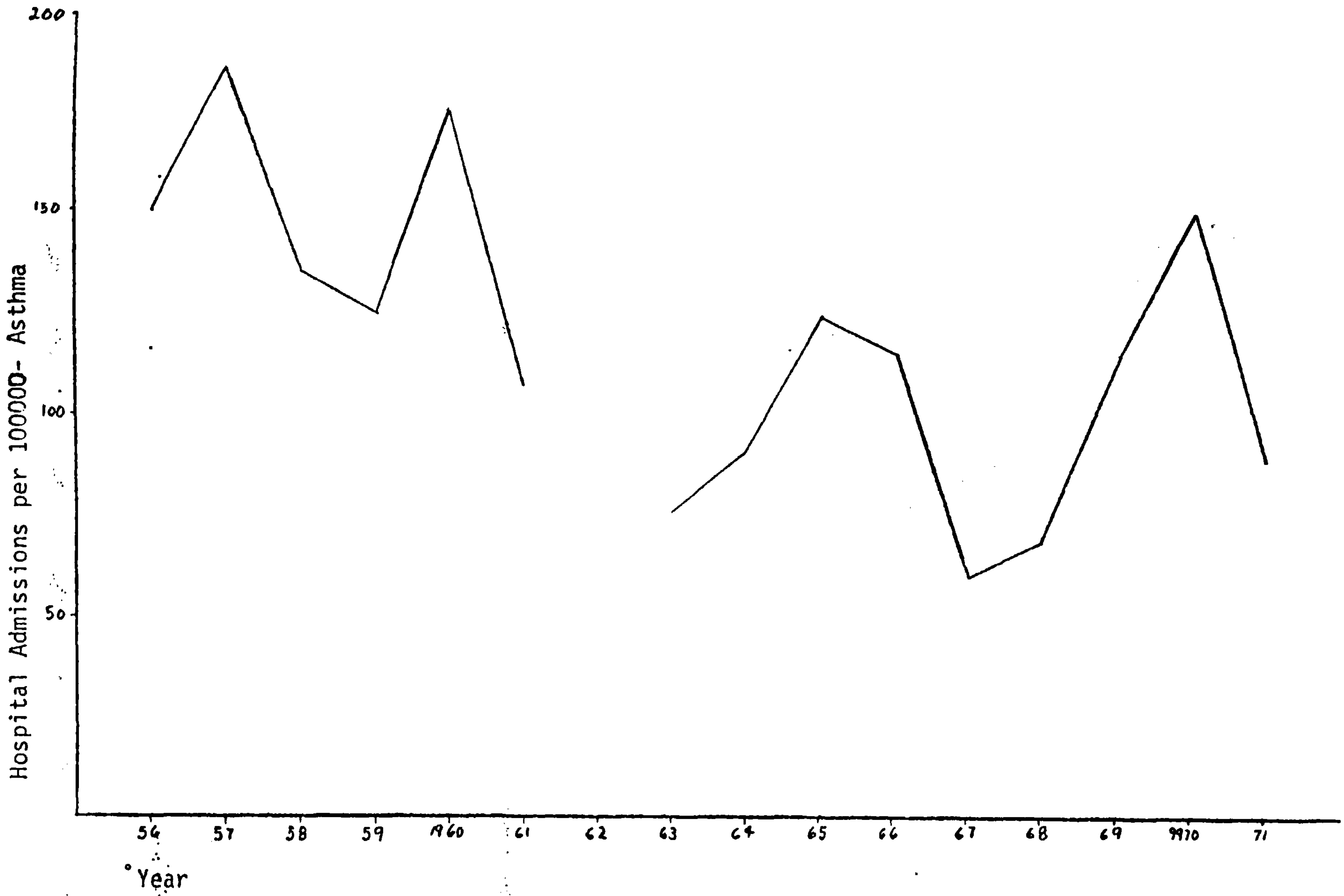


Figure 1.4

Asthma admissions to St. Patrick's Hospital 1956-1971

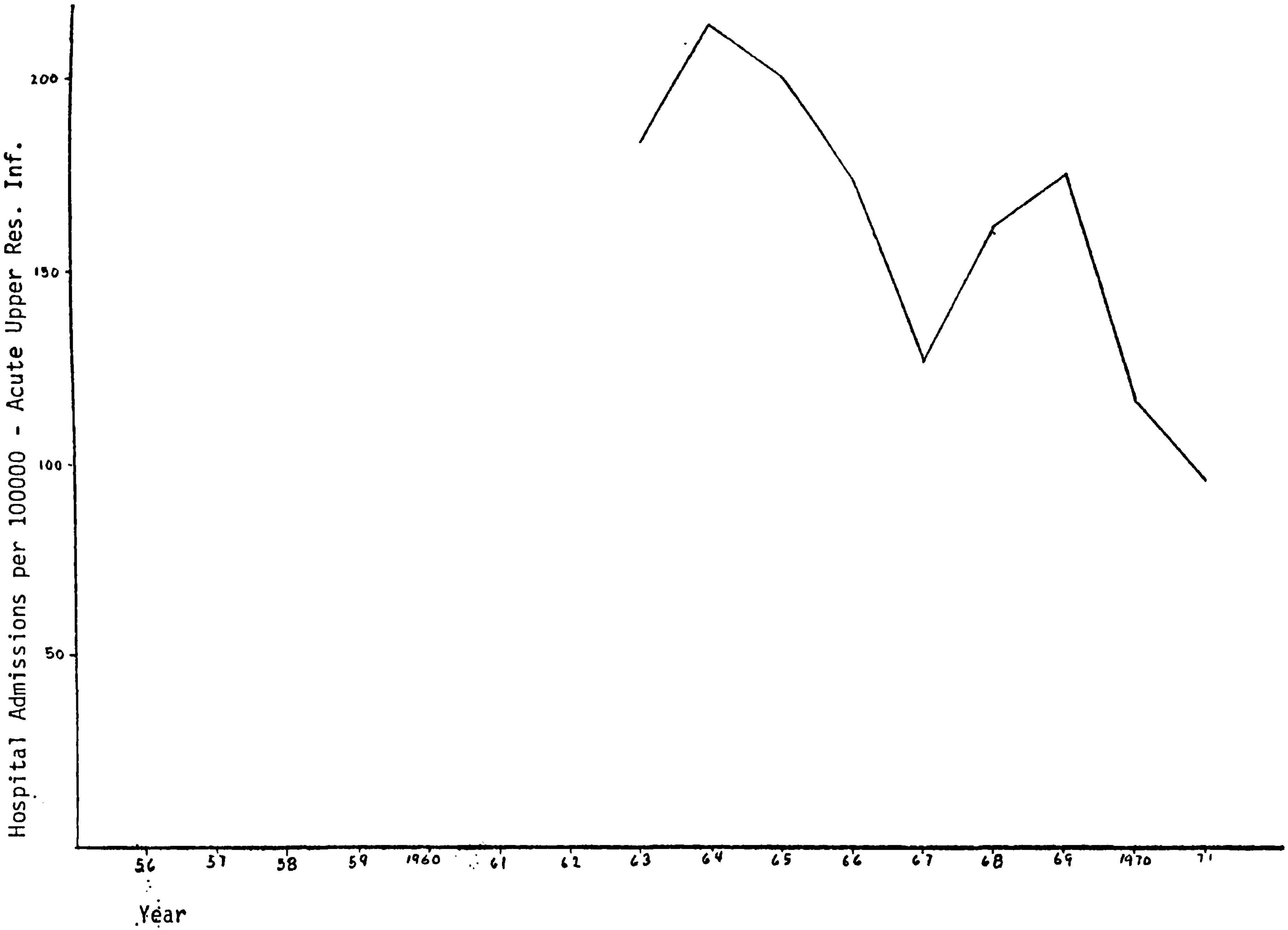


Figure 1.5

Acute Upper Respiratory Infection Admissions to St. Patrick's Hospital 1963 - 1971

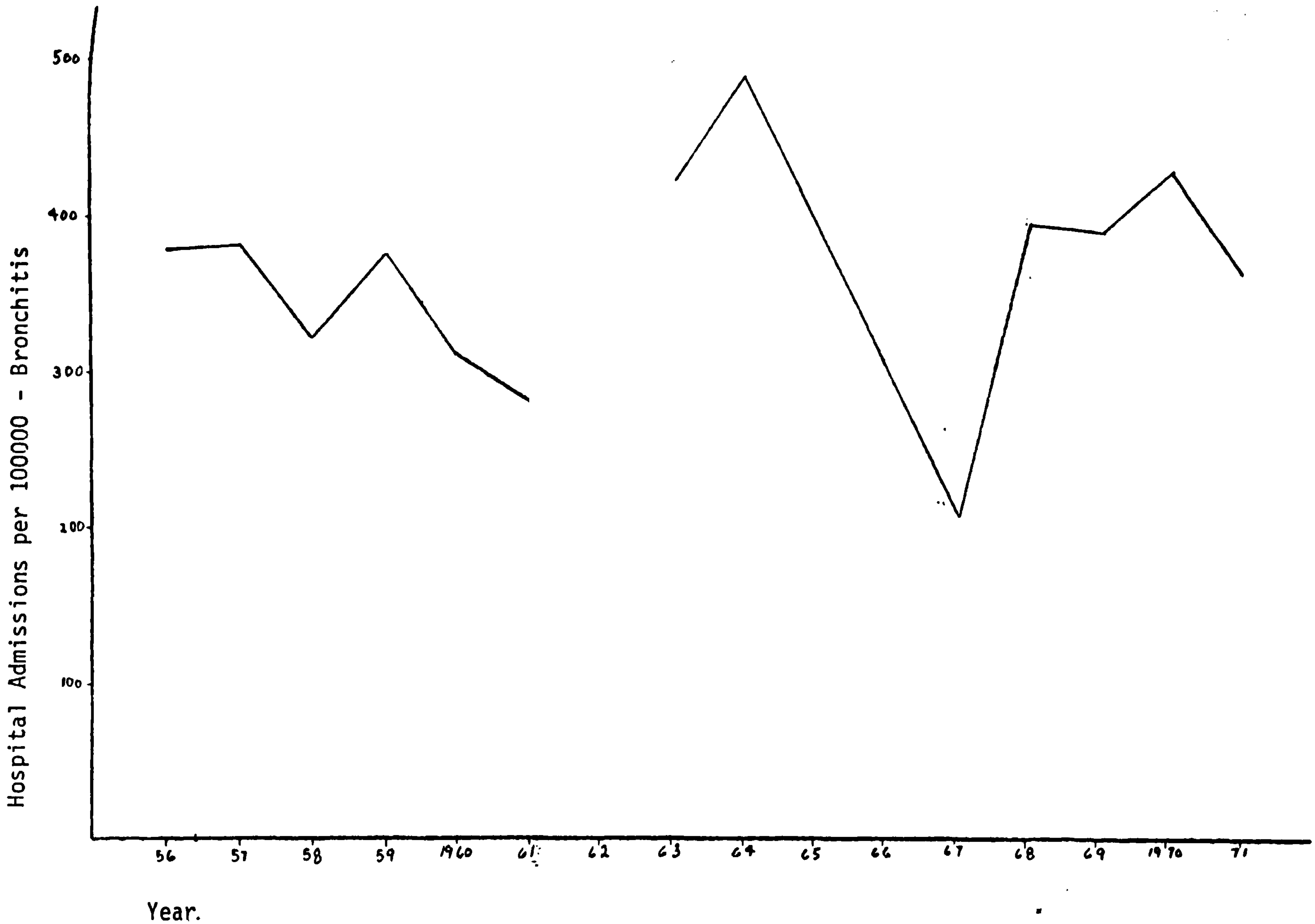


Figure 1.6

Bronchitis Admissions to St. Patrick's Hospital 1956-1971

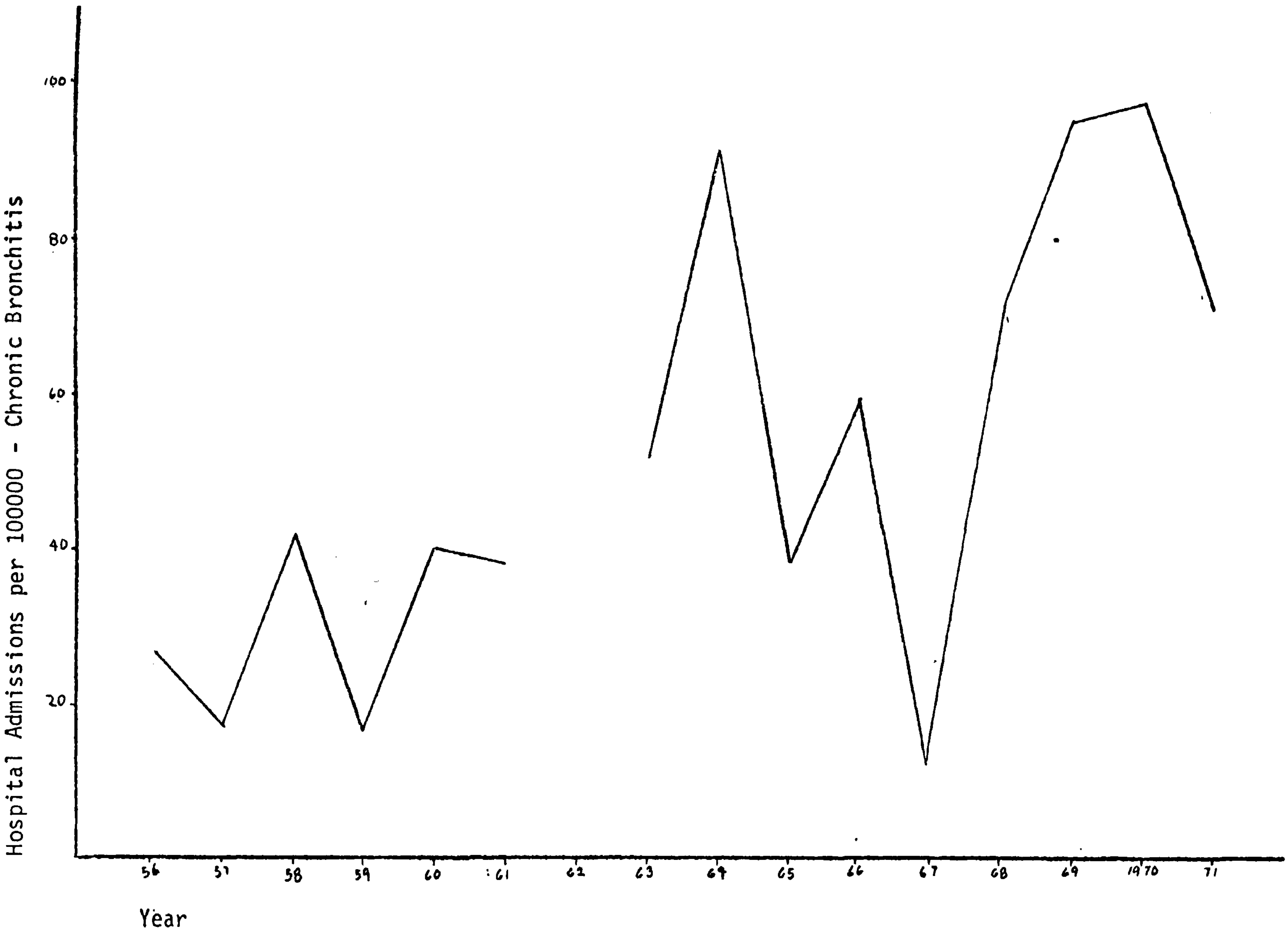


Figure 1.7

Chronic Bronchitis Admissions to St. Patrick's Hospital 1956-1971

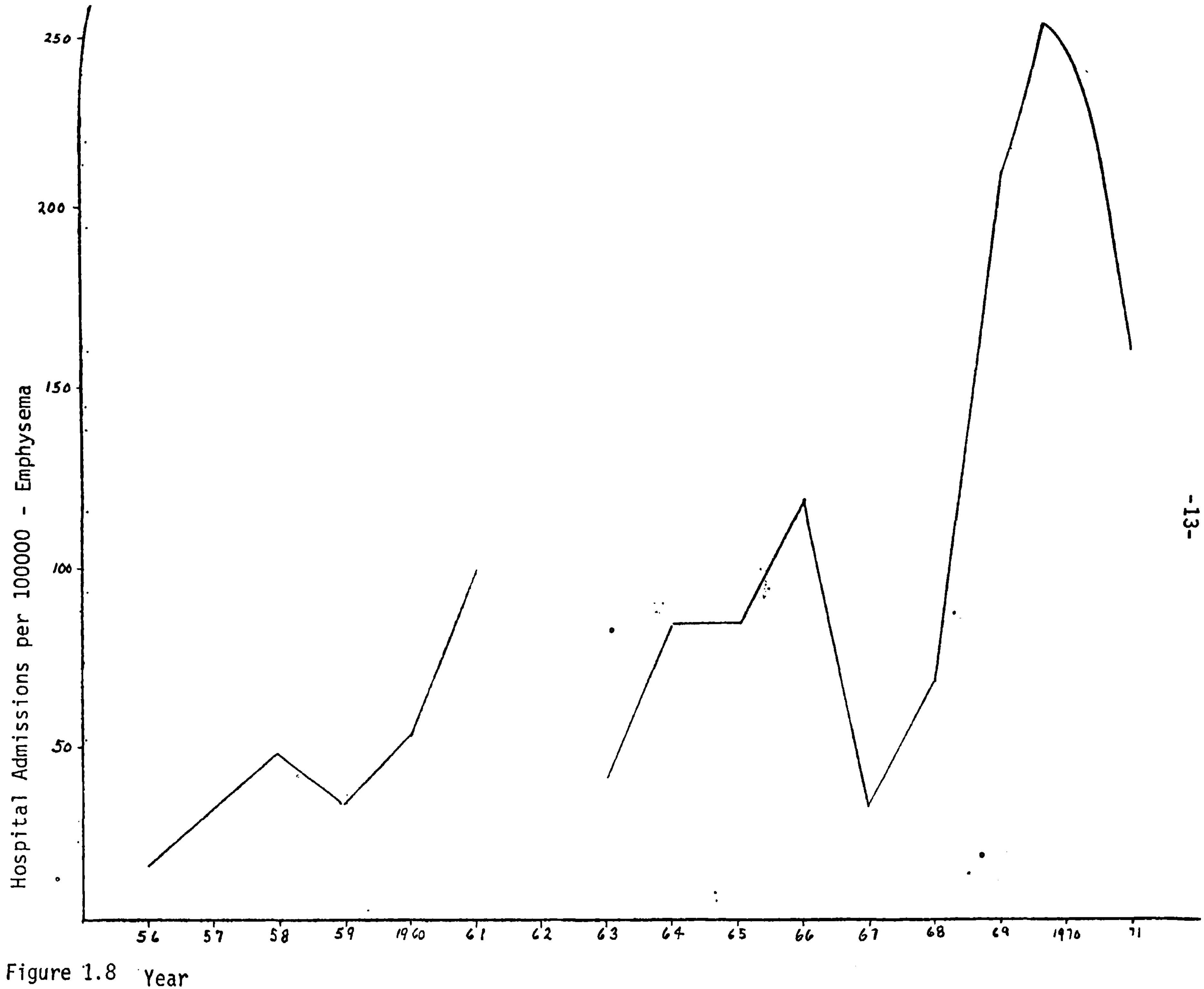


Figure 1.8

Emphysema Admissions to St. Patrick's Hospital 1956-1971

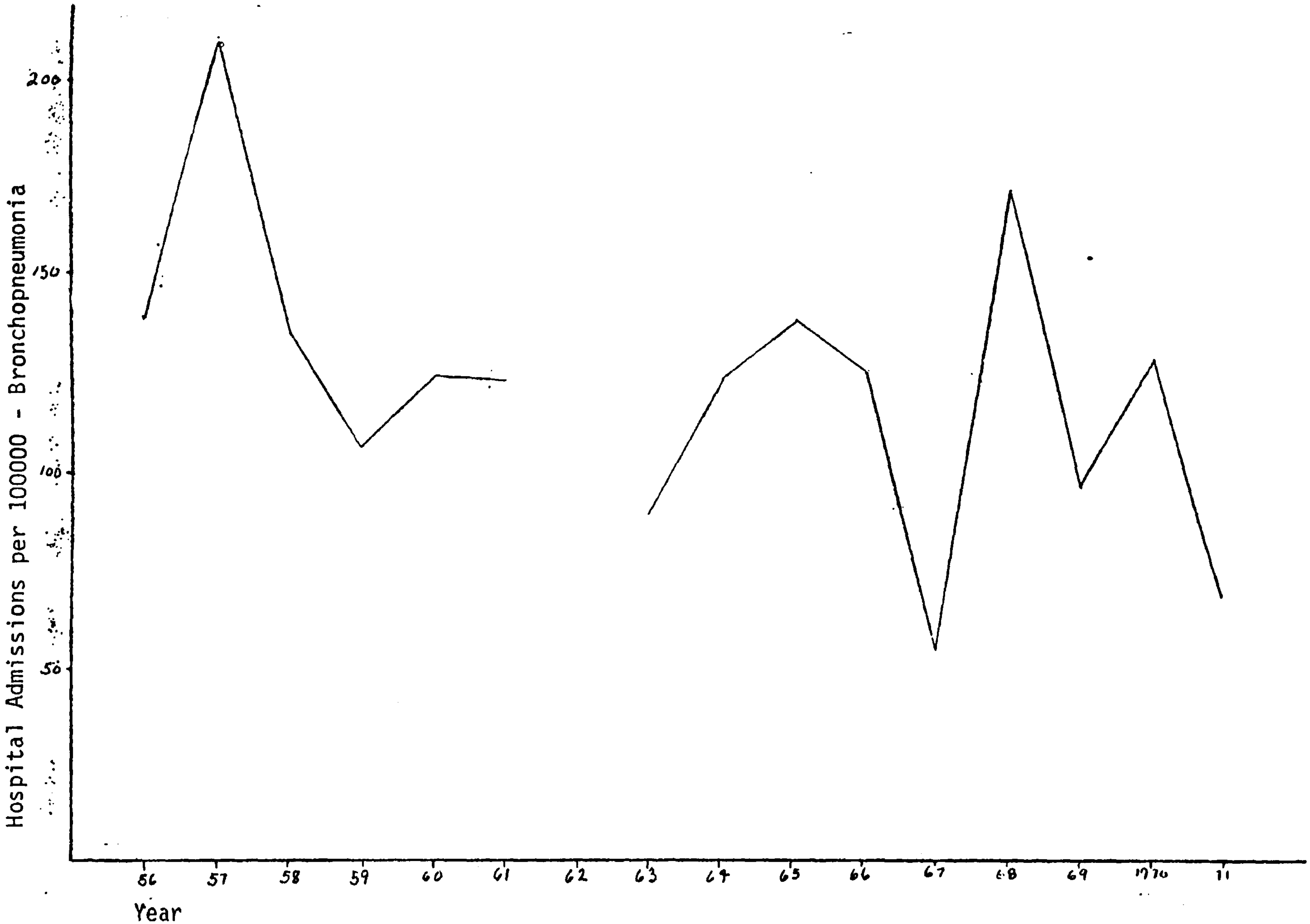


Figure 1.9

Bronchopneumonia Admissions to St. Patrick's Hospital 1956 - 1971

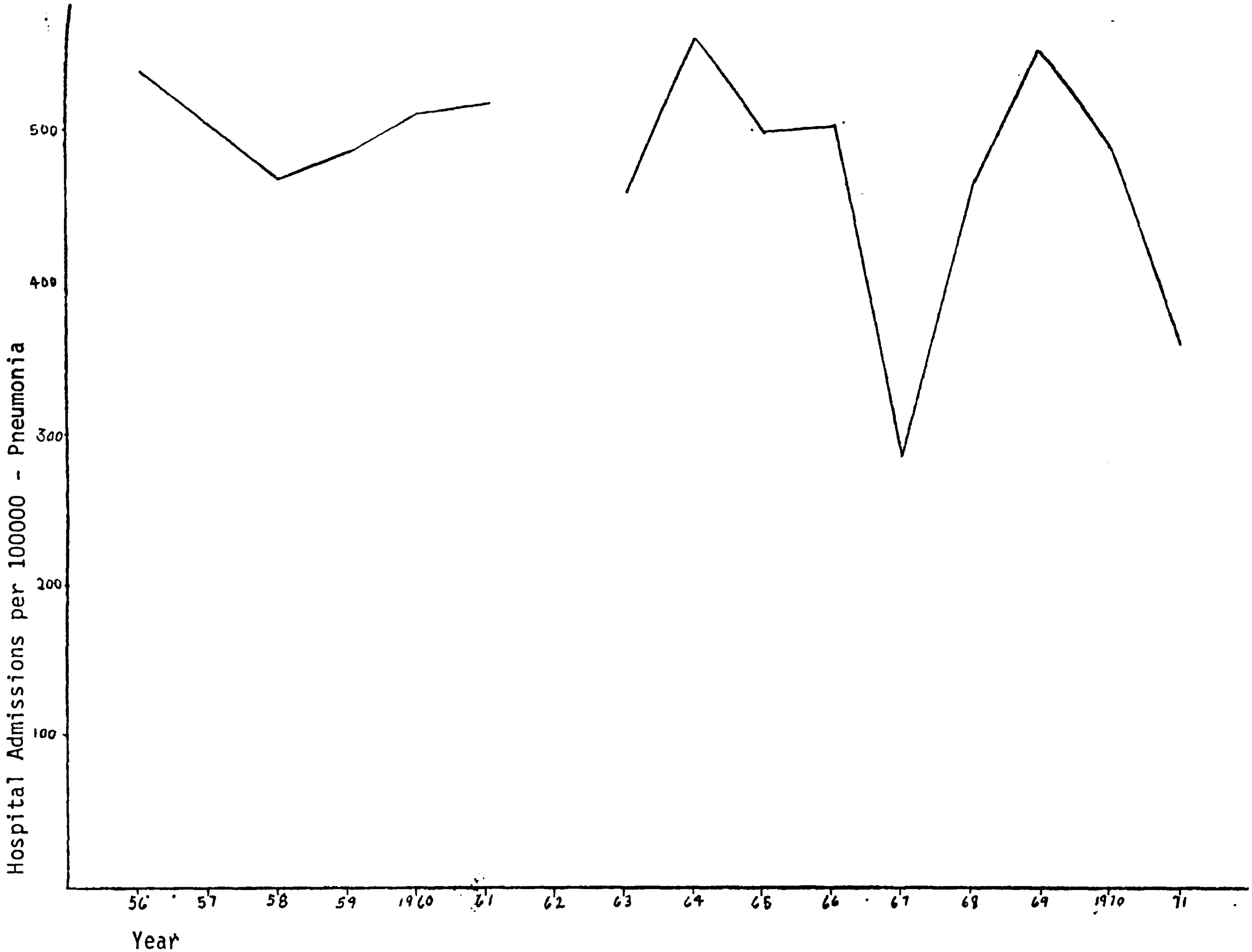


Figure 1.10

Pneumonia Admissions to St. Patrick's Hospital 1956 - 1971

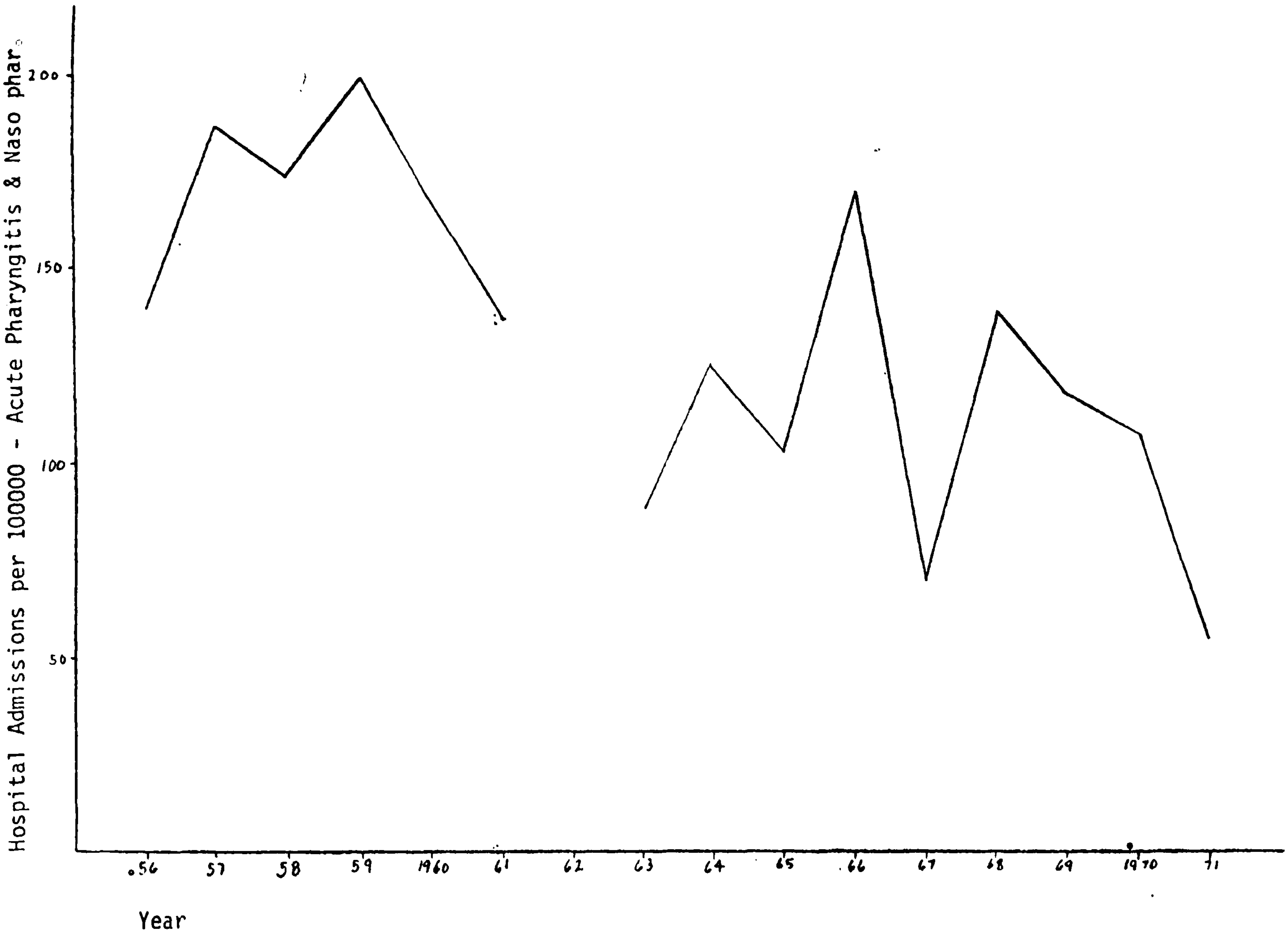


Figure 1.11

Acute pharyngitis and Nasopharyngitis Admissions to St. Patrick's Hospital 1956 - 1971

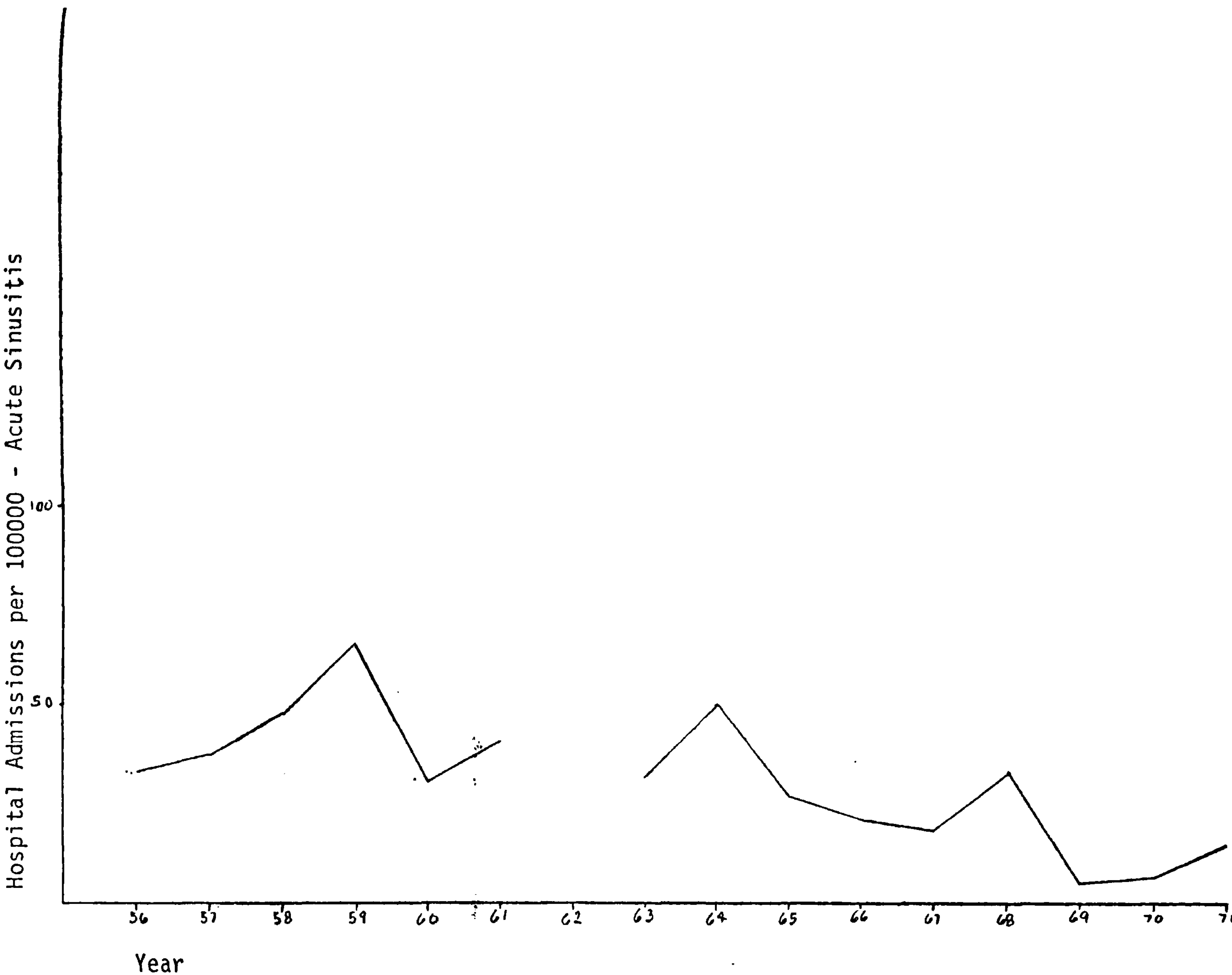


Figure 1.12

Acute Sinusitis Admissions to St. Patrick's Hospital 1956 - 1971

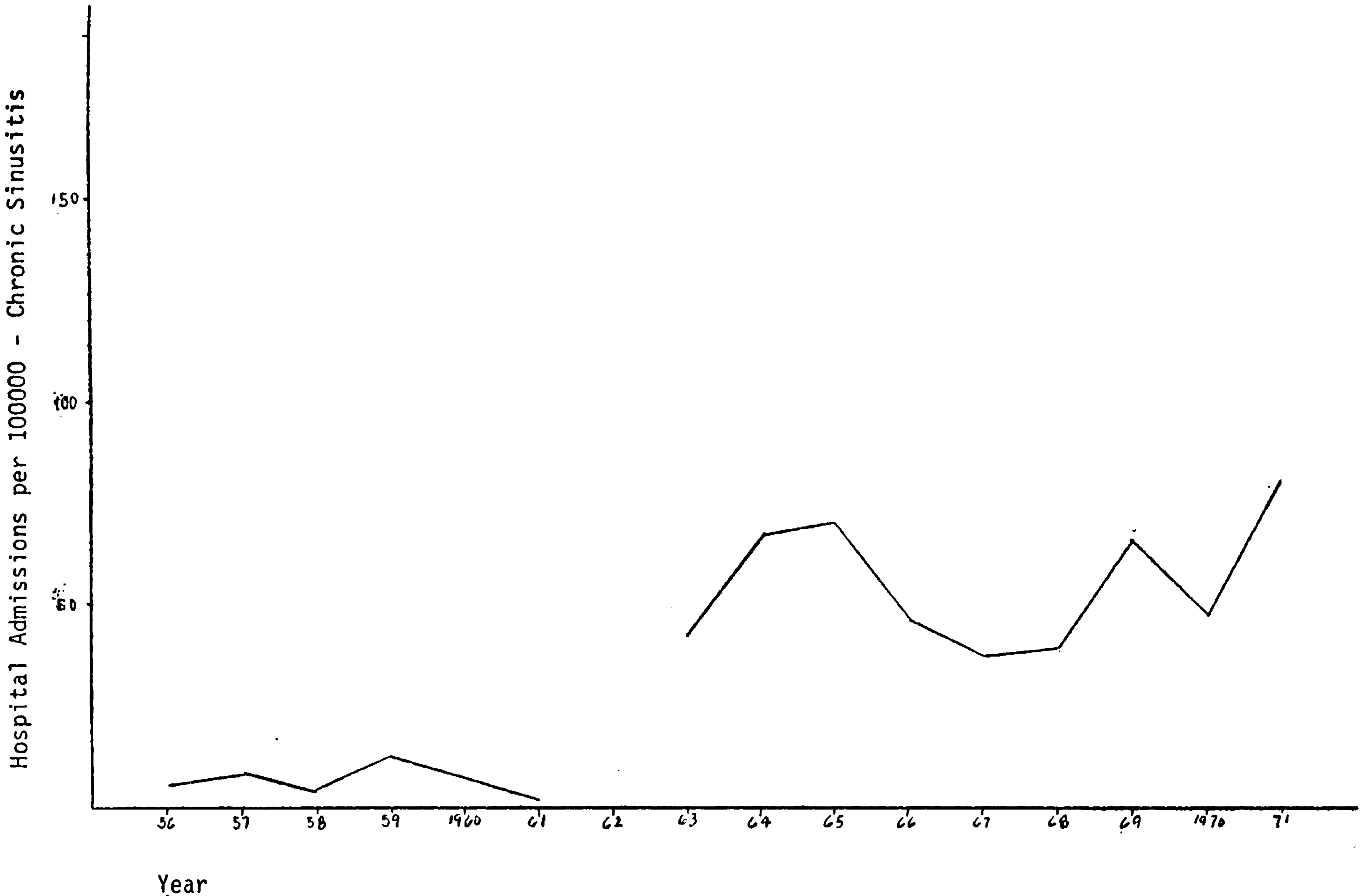
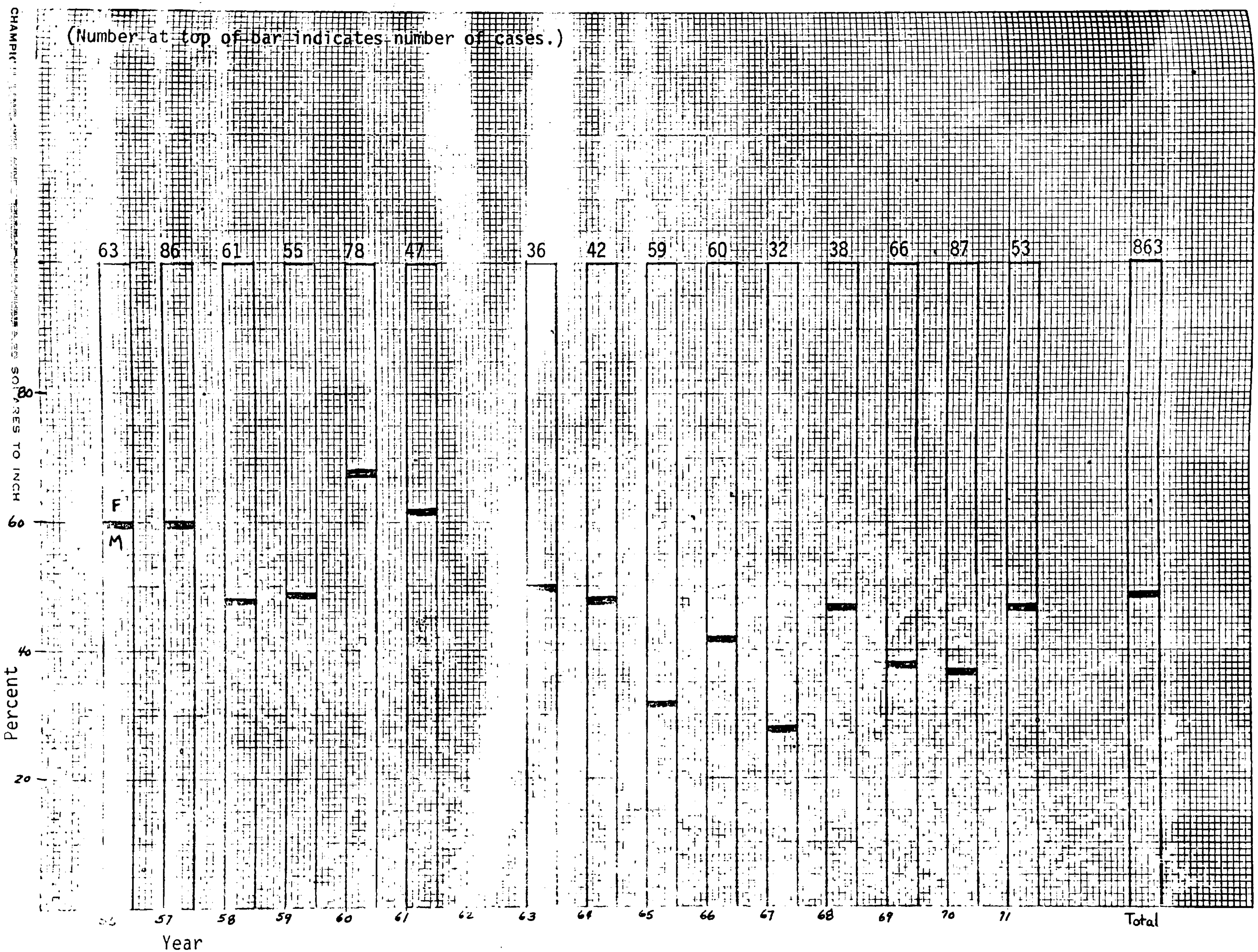
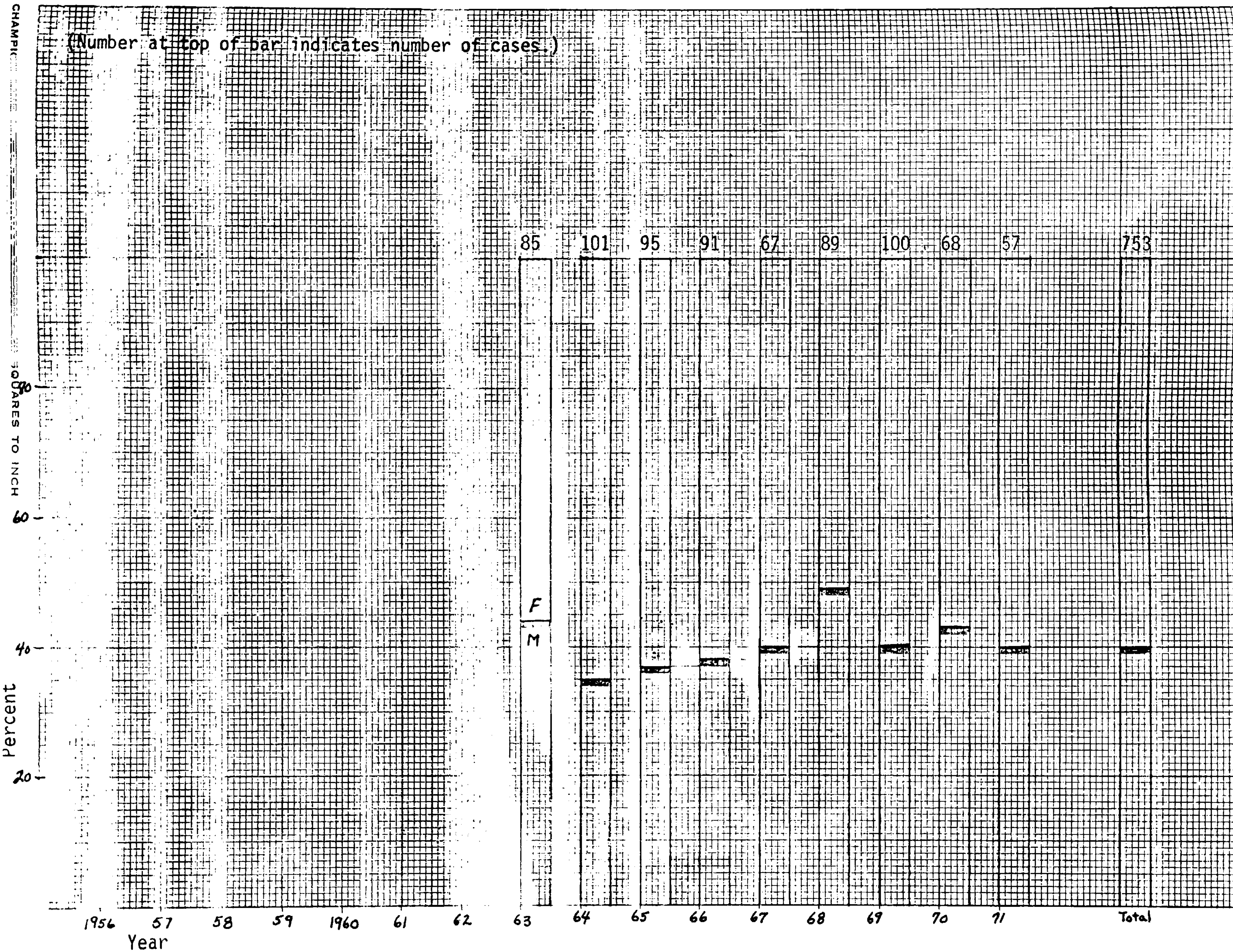


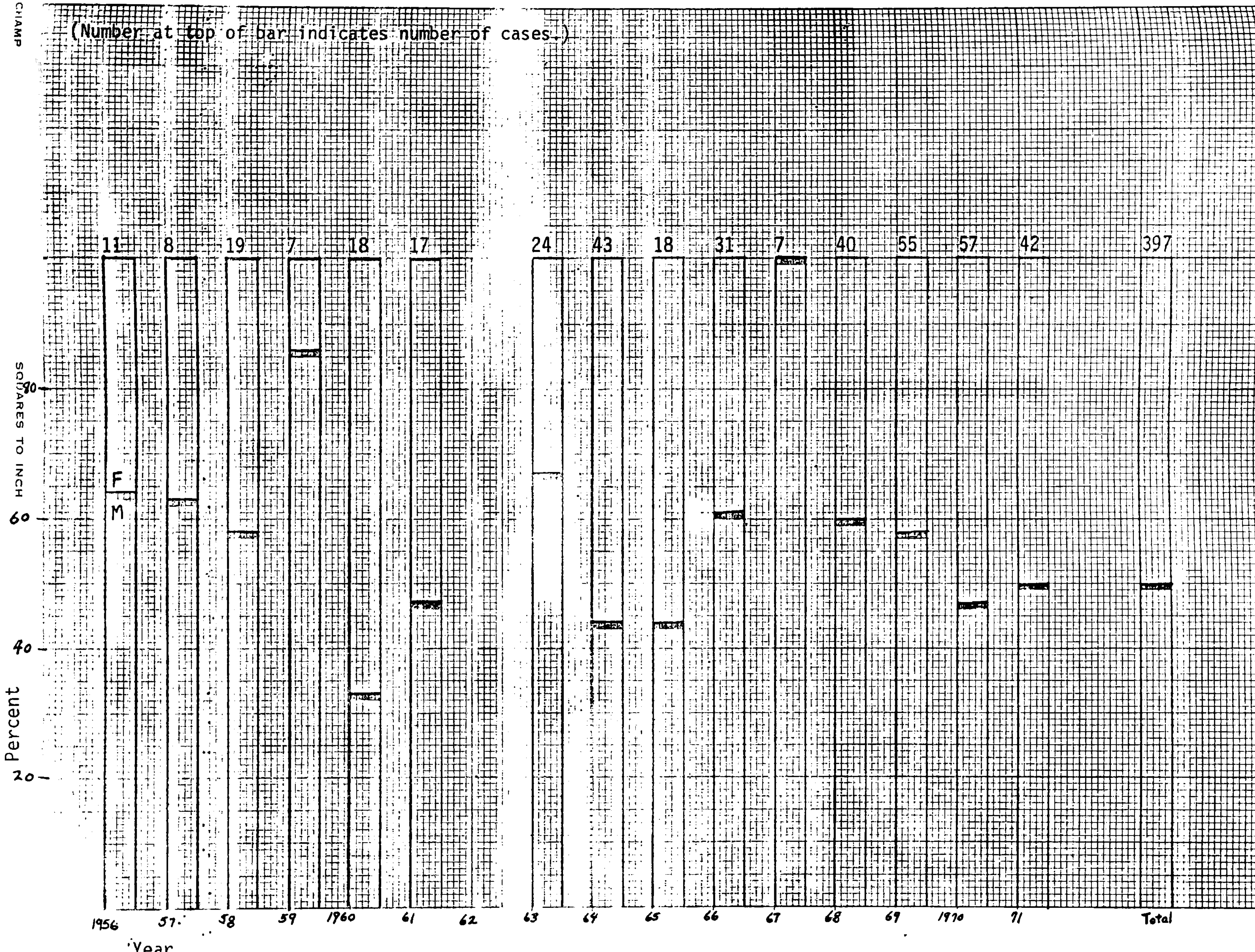
Figure 1.13

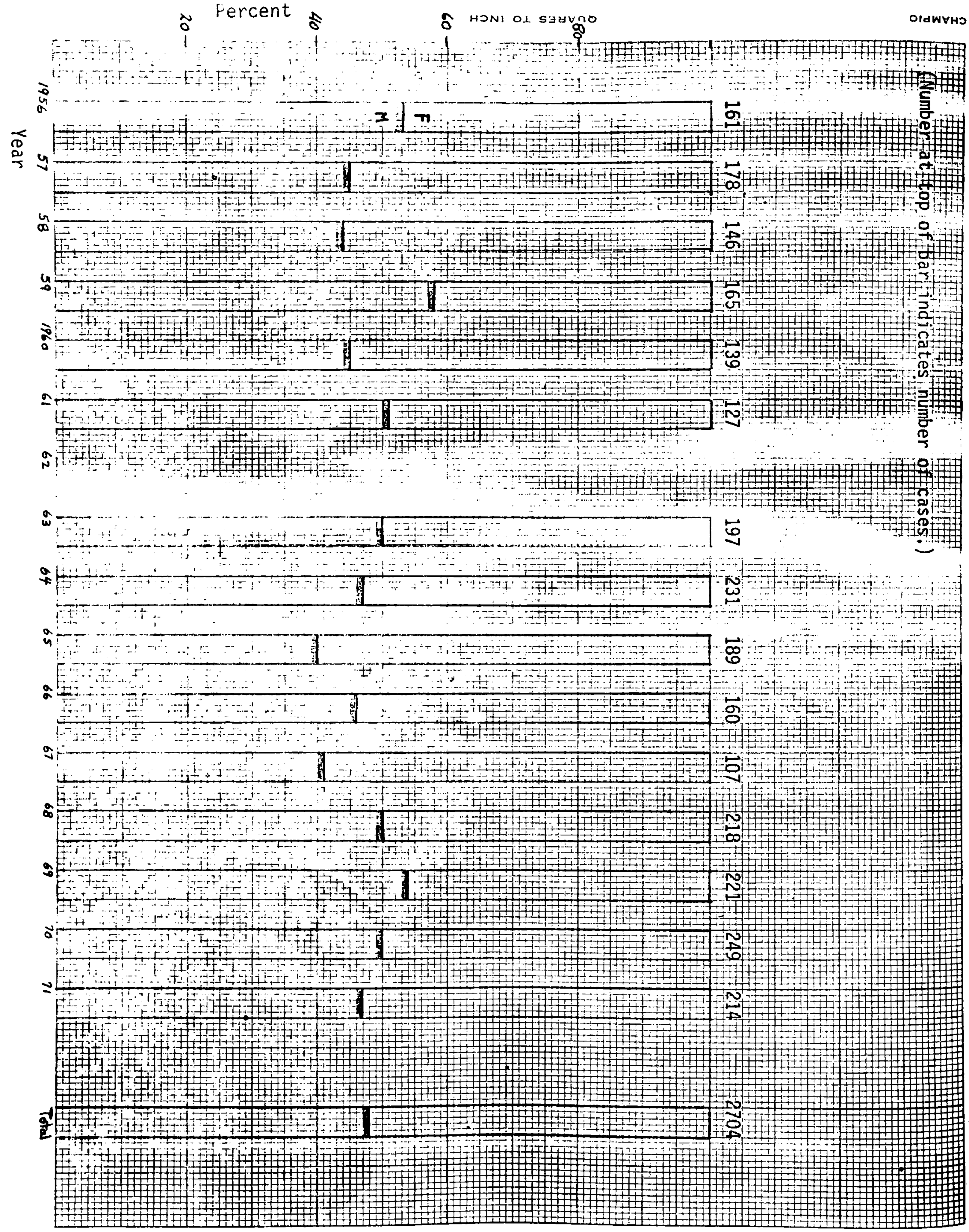
Chronic Sinusitis Admissions to St. Patrick's Hospital 1956-1971


(Number at top of bar indicates number of cases.)
63
86
61
55
78
47
36
42
59
60
32
38
66
87
53
863
80
60
40
20
Percent
F
M
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
Total
Year

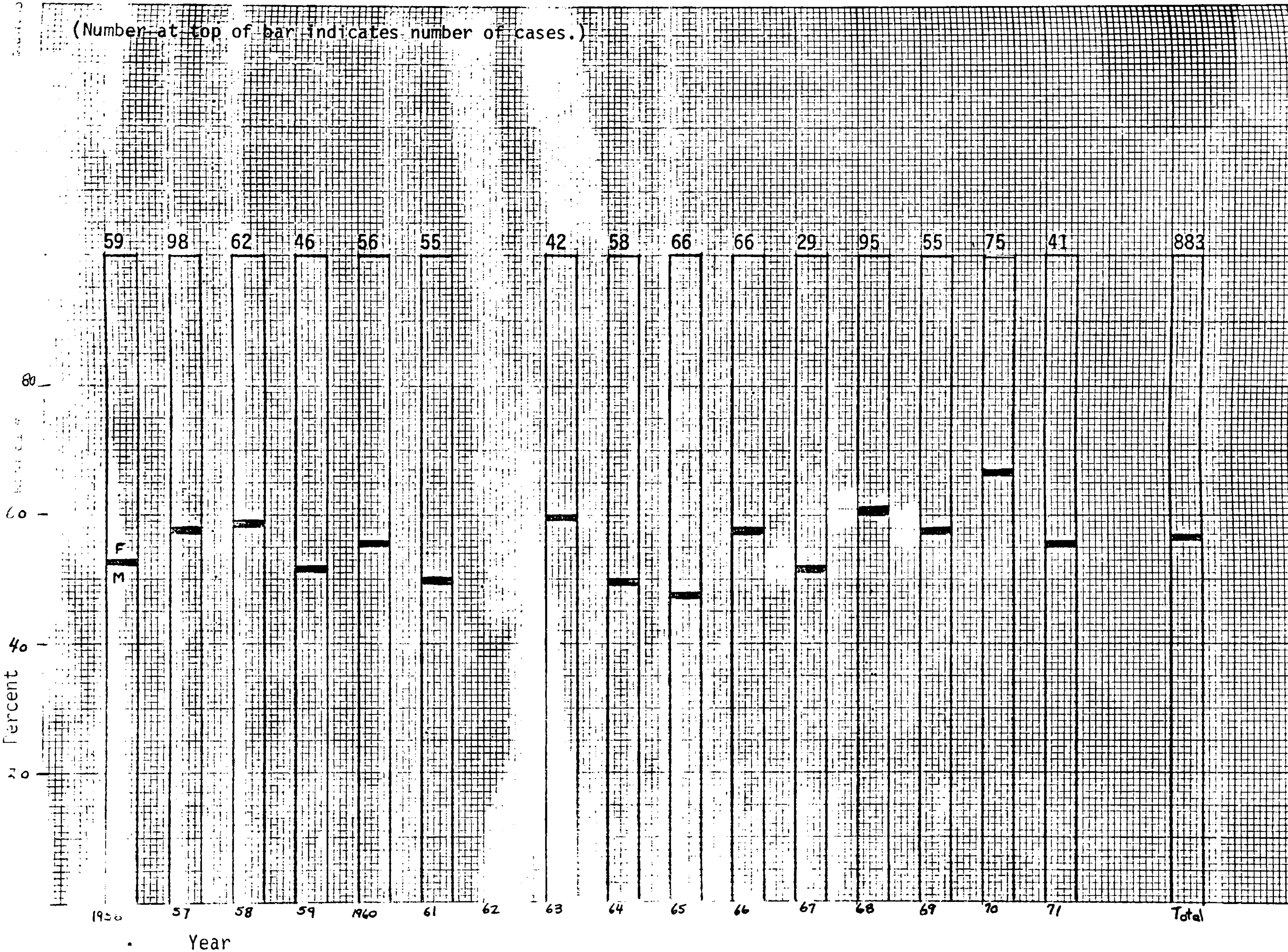

(Number at top of bar indicates number of cases.)
85
101
95
91
67
89
100
68
57
753
F
M
Percent
20
40
60
80
1956
57
58
59
1960
61
62
63
64
65
66
67
68
69
70
71
Total
Year
CHAMPION
SQUARES TO INCH

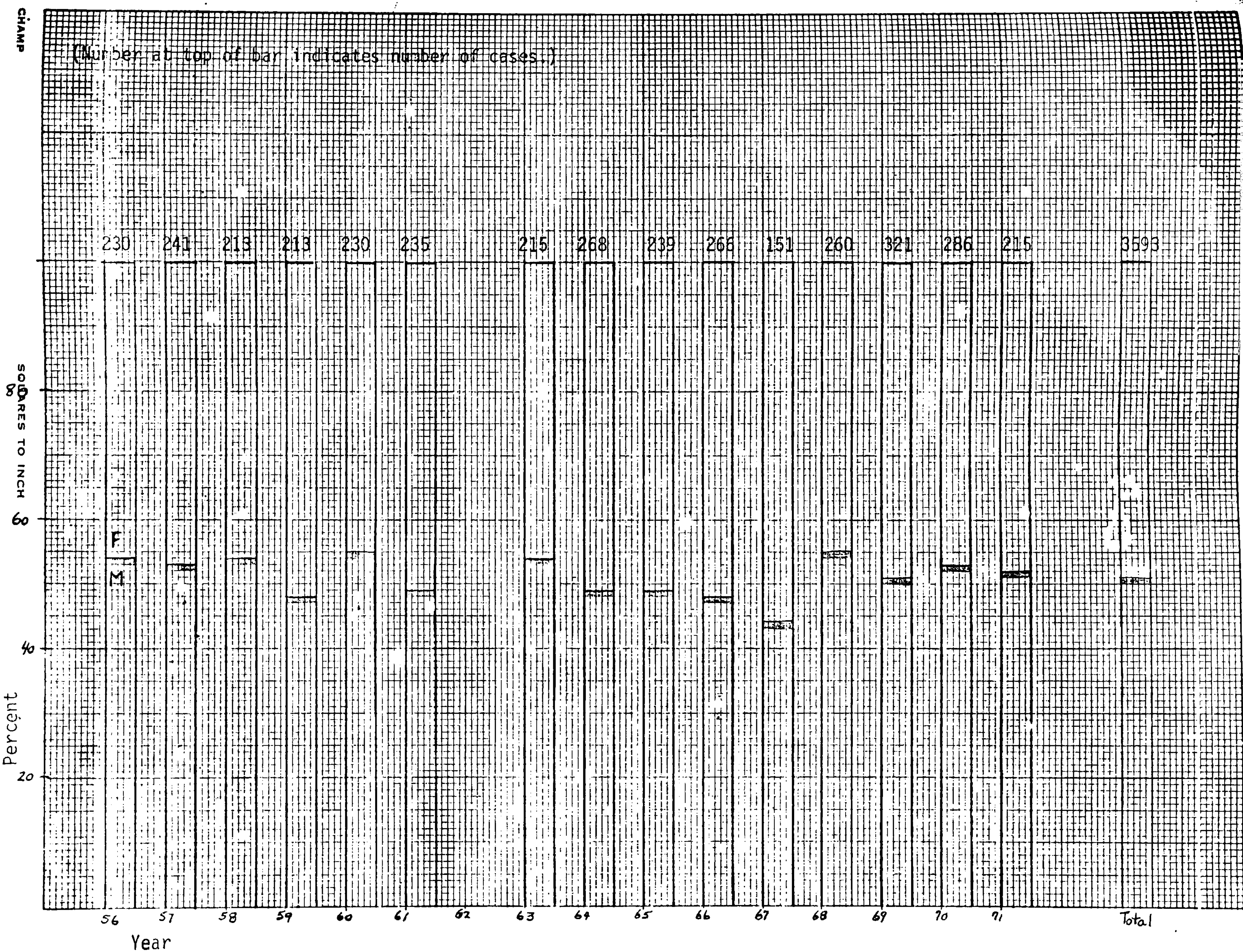
Sexual Differentiation - Chronic Bronchitis



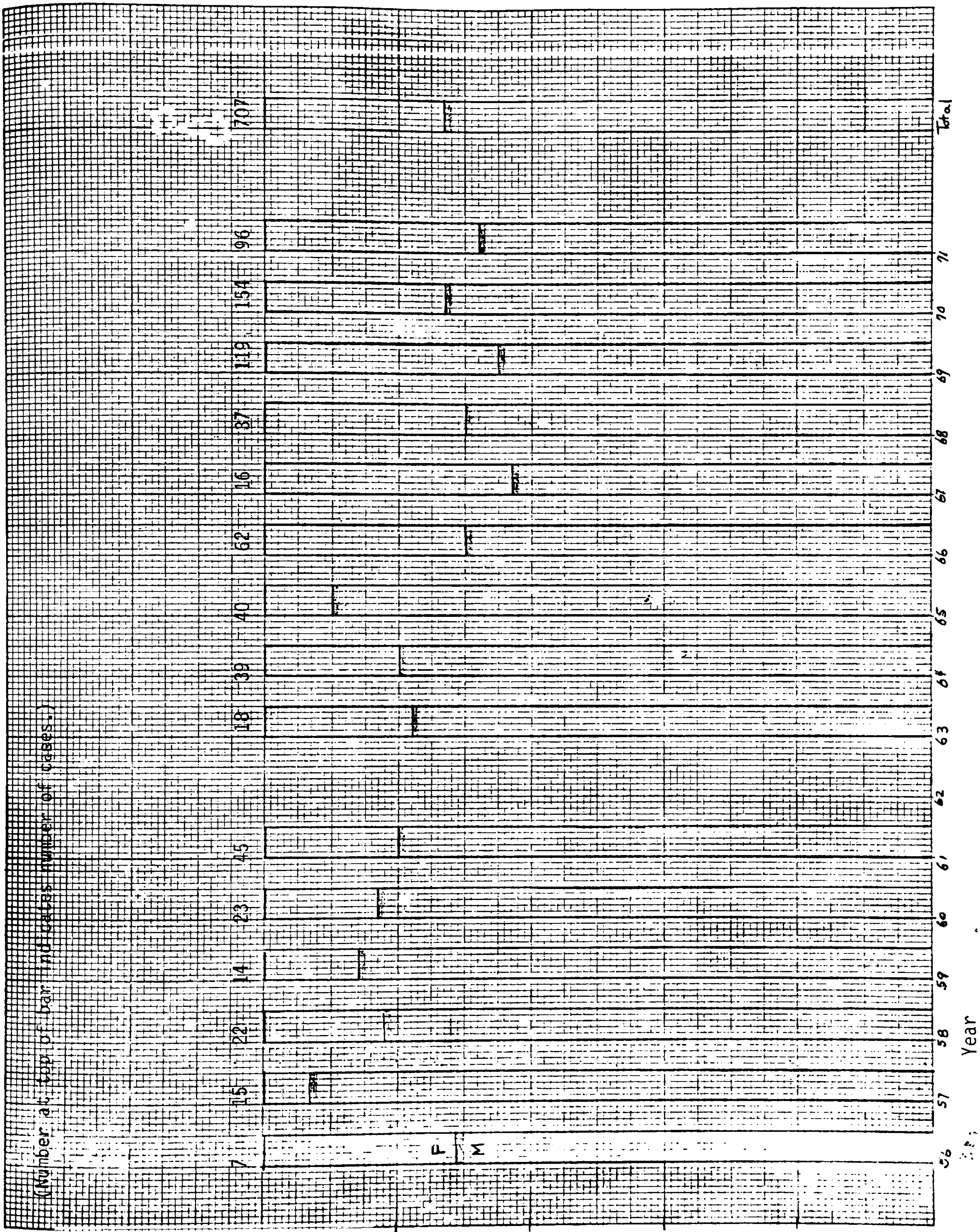

Percent
20
40
60
80
(Number at top of bar indicates number of cases.)
M
F
Year
1956
57
58
59
1960
61
62
63
64
65
66
67
68
69
70
71
Total
161
178
146
165
139
127
197
231
189
160
107
218
221
249
214
2704

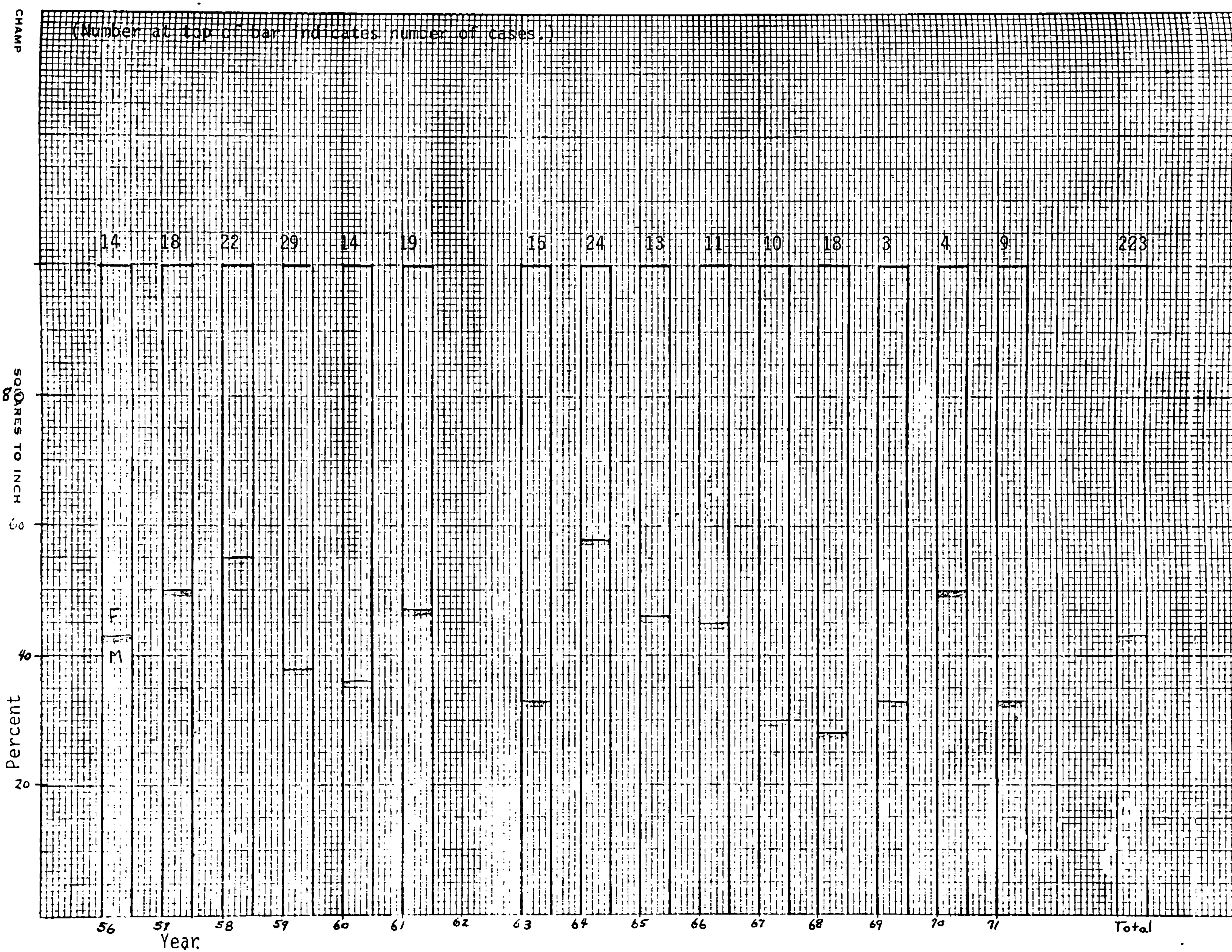
Sexual Differentiation - Bronchopneumonia Figure 1.18





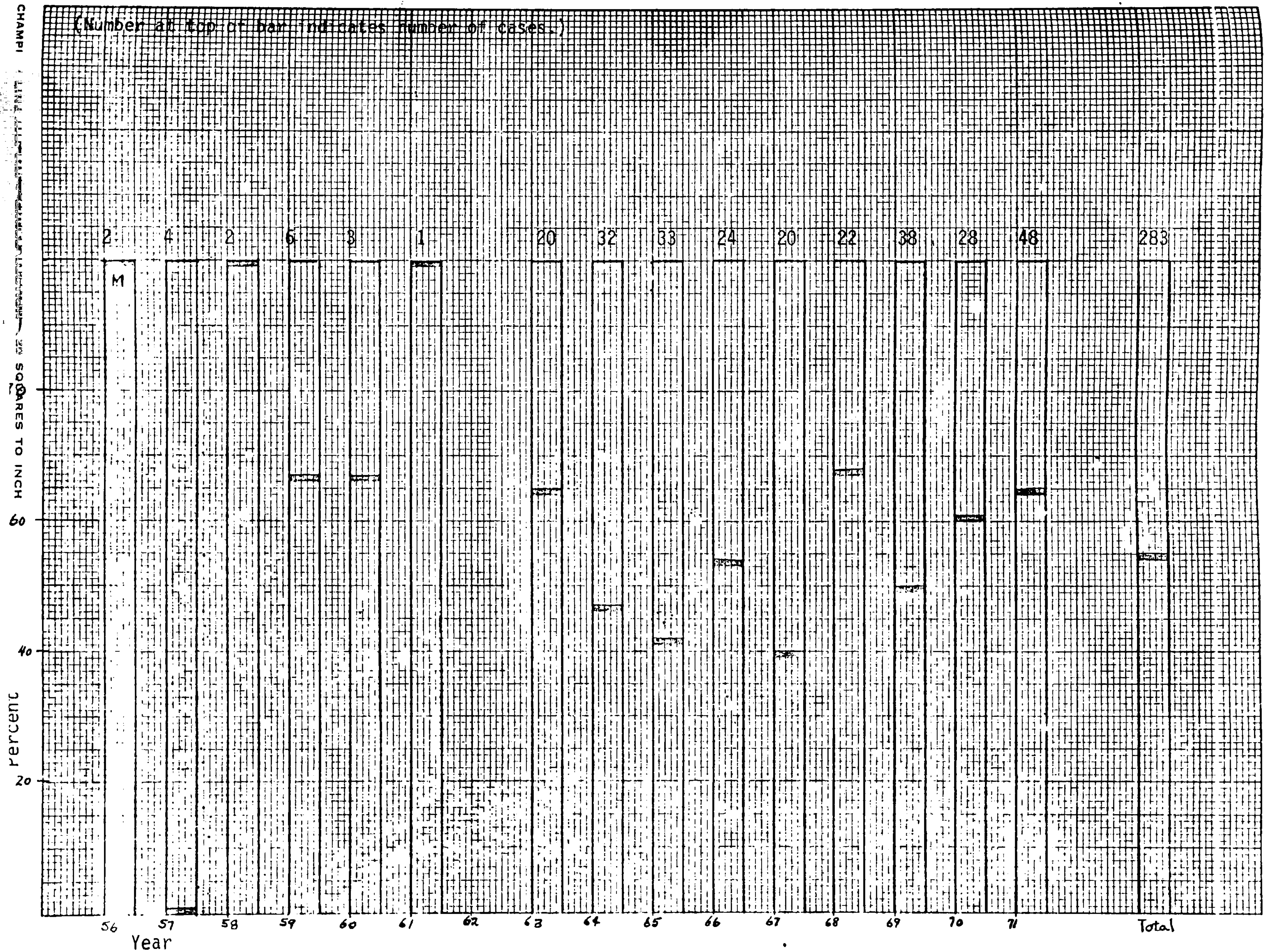
(Number at top of bar indicates number of cases.)
230
241
213
213
230
235
215
268
239
266
151
260
321
286
215
3593
F
M
80
60
40
20
Percent
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
Total
Year


(Number at top of bar indicates number of cases.)
7
15
22
14
23
45
18
39
40
62
16
37
119
154
96
707
F
M
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
Total
Year
60
40
20
Percent

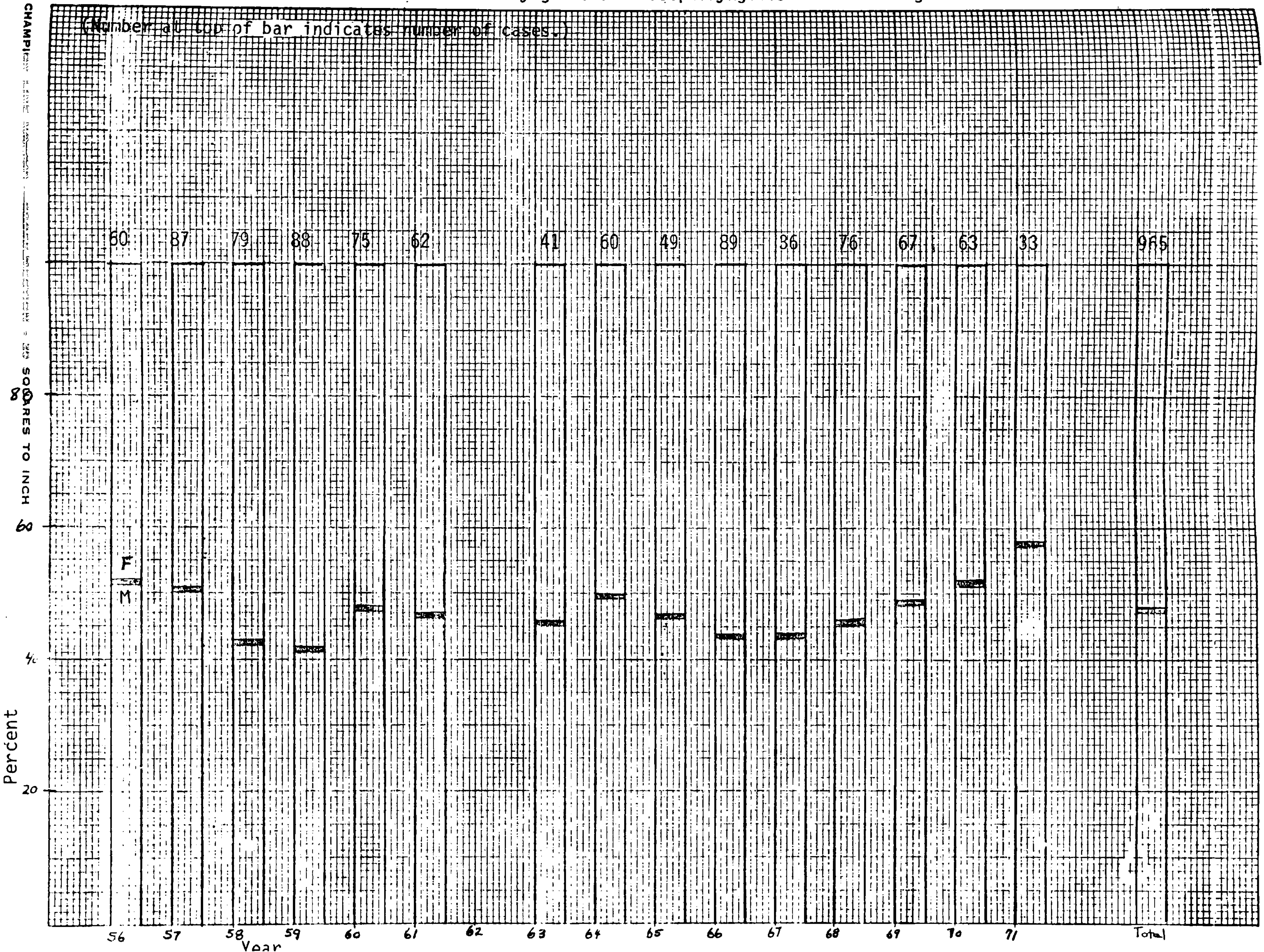

(Number at top of bar indicates number of cases.)
14
18
22
29
14
19
15
24
13
11
10
18
3
4
9
223
F
M
Percent
80
60
40
20
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
Total
Year
CHAMP
SQUARES TO INCH

Sexual Differentiation - Chronic Sinusitis

Figure 1.22



Sexual Differentiation - Acute Pharyngitis and Nasopharyngitis Figure 1.23



AGE GROUP (.PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	29	2	0	3	6	8	22	22	8	63
1957	31	5	5	3	6	7	13	19	12	86
1958	18	0	0	0	16	8	26	23	8	61
1959	22	4	2	4	2	13	22	20	13	55
1960	13	6	1	4	12	12	23	13	17	78
1961	21	11	4	2	11	11	19	13	9	47
1962										
1963	11	14	6	0	8	17	19	11	14	36
1964	17	7	0	0	9	19	7	14	26	42
1965	12	20	0	2	10	12	7	5	32	59
1966	12	20	5	0	12	3	17	13	18	60
1967	19	19	3	3	16	16	6	6	12	32
1968	13	8	3	3	5	13	21	18	16	38
1969	12	8	2	0	8	8	27	17	20	66
1970	15	8	5	6	10	7	24	10	15	87
1971	19	4	8	0	21	4	15	23	8	53
TOTAL	18	8	3	2	10	10	19	15	15	863

Figure 1.24

Age Differentiation - Asthma

YEAR	AGE GROUP (PERCENT) 0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956										
1957										
1958										
1959										
1960										
1961										
1962										
1963	31	4	2	4	12	13	11	7	18	85
1964	25	3	2	5	21	7	14	6	18	101
1965	38	7	3	9	6	3	11	6	16	95
1966	27	3	4	9	15	11	8	12	9	91
1967	34	0	6	4	12	4	13	9	16	67
1968	36	6	3	4	10	7	8	9	17	89
1969	41	2	3	7	13	4	6	4	20	100
1970	29	1	7	6	10	10	10	9	16	68
1971	30	5	4	7	12	12	4	5	21	57
TOTAL	33	4	4	6	13	8	9	7	17	753

Figure 1.25

Age Differentiation - Acute Upper Respiratory Infection

AGE GROUP (.PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	0	0	0	0	18	18	27	27	9	11
1957	0	0	0	13	38	13	38	0	0	8
1958	0	0	0	5	11	16	32	21	16	19
1959	0	0	0	0	14	43	14	0	29	7
1960	0	0	0	6	17	11	17	44	6	18
1961	0	0	0	0	24	12	29	18	18	17
1962										
1963	0	0	4	0	17	8	13	38	21	24
1964	12	2	0	5	5	16	26	23	12	43
1965	0	0	0	0	6	28	50	0	17	18
1966	0	0	0	0	6	6	42	29	16	31
1967	14	0	0	0	14	0	14	29	29	7
1968	3	3	3	0	3	8	40	23	20	40
1969	7	0	2	0	5	9	22	29	25	55
1970	5	0	0	0	7	11	26	25	26	57
1971	0	2	0	0	2	10	36	19	31	42
TOTAL	4	1	1	1	9	12	29	24	20	397

Figure 1.26

Age Differentiation - Chronic Bronchitis

YEAR	AGE GROUP (PERCENT) 0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	30	9	5	4	14	8	12	11	6	161
1957	38	6	3	6	11	12	12	6	6	178
1958	31	5	2	5	10	11	15	12	8	146
1959	27	2	5	5	12	12	13	13	10	165
1960	33	4	4	6	12	9	11	14	8	139
1961	37	9	3	3	14	6	13	8	6	127
1962										
1963	21	11	5	3	13	15	11	11	10	197
1964	32	5	1	4	8	15	16	10	10	231
1965	23	4	4	3	12	15	14	10	16	189
1966	21	6	3	4	9	11	20	13	14	160
1967	27	2	2	2	15	6	16	13	18	107
1968	28	4	3	5	12	5	17	12	14	218
1969	27	5	2	4	7	6	16	14	19	221
1970	27	4	3	2	10	9	16	14	16	249
1971	26	6	0	3	8	6	18	15	16	214
TOTAL	28	5	3	4	11	10	15	12	12	2704

Figure 1.27

Age Differentiation - Bronchitis

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	29	5	0	2	16	9	12	7	21	59
1957	32	11	3	1	2	4	15	20	13	98
1958	44	0	0	2	2	7	6	17	22	62
1959	25	9	0	0	18	5	5	16	23	46
1960	31	13	4	4	5	13	7	11	13	56
1961	40	14	4	2	6	4	10	4	16	55
1962										
1963	38	2	2	0	10	2	12	10	24	42
1964	40	3	2	0	10	9	10	9	17	58
1965	33	11	3	3	5	5	15	9	17	66
1966	38	5	3	0	9	8	9	9	20	66
1967	52	0	0	0	10	7	3	14	14	29
1968	41	9	2	1	7	4	8	9	17	95
1969	53	6	4	0	6	2	4	6	18	55
1970	47	7	1	1	5	8	5	7	19	75
1971	56	5	5	2	2	0	2	7	20	41
TOTAL	39	7	2	1	7	6	9	11	18	883

Figure 1.28

Age Differentiation - Bronchopneumonia

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	20	4	4	3	18	12	12	9	17	230
1957	25	10	5	3	12	8	11	14	14	241
1958	27	4	2	2	10	10	13	15	17	213
1959	15	5	3	2	19	10	14	8	23	213
1960	18	7	3	7	9	11	14	13	17	230
1961	21	8	8	4	11	11	10	9	18	235
1962										
1963	14	4	4	4	13	11	17	11	21	215
1964	24	3	2	5	12	9	11	12	23	268
1965	22	11	3	5	10	9	11	9	20	239
1966	16	6	6	3	12	11	9	14	22	266
1967	23	7	3	1	15	6	7	15	24	151
1968	25	7	3	2	10	8	10	13	23	260
1969	27	6	2	4	8	6	10	11	27	321
1970	27	6	2	2	8	8	10	12	23	286
1971	33	5	5	4	7	5	8	13	21	215
TOTAL	23	6	4	3	12	9	11	12	21	3593

Figure 1.29

Age Differentiation - Pneumonia

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	0	0	0	0	14	0	0	57	29	7
1957	13	0	0	0	7	7	13	27	33	15
1958	5	0	0	0	0	0	5	41	50	22
1959	0	0	0	0	0	0	29	36	36	14
1960	0	0	0	0	0	0	26	39	35	23
1961	0	2	0	0	2	0	24	40	31	45
1962										
1963	0	0	0	0	0	11	11	56	22	18
1964	3	0	0	0	0	5	18	31	44	39
1965	0	3	0	0	3	5	15	43	33	40
1966	0	0	0	0	2	0	21	31	47	62
1967	0	0	0	0	0	13	25	31	13	16
1968	0	3	0	0	0	0	22	35	41	37
1969	0	0	0	0	2	4	33	27	45	119
1970	1	0	0	1	2	3	23	23	47	154
1971	0	0	0	1	2	6	7	32	51	96
TOTAL	1	0	0	0	2	4	19	32	43	707

Figure 1.30

Age Differentiation - Emphysema

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	7	7	7	7	36	14	14	7	0	14
1957	0	6	11	33	22	11	6	0	11	18
1958	0	9	0	9	41	23	14	9	0	22
1959	0	21	0	10	17	10	24	7	10	29
1960	7	7	7	0	29	7	14	21	7	14
1961	0	11	0	0	32	42	11	5	0	19
1962										
1963	0	7	13	13	0	20	20	13	13	15
1964	0	0	4	8	42	21	17	8	0	24
1965	0	7	0	15	23	23	7	23	0	13
1966	0	0	9	18	9	9	18	18	18	11
1967	10	10	0	0	40	10	20	0	10	10
1968	6	0	0	0	50	11	11	17	6	18
1969	0	0	0	33	0	33	33	0	0	3
1970	0	0	0	0	50	25	0	25	0	4
1971	11	22	11	0	11	11	22	0	11	9
TOTAL	2	8	4	9	28	17	15	10	6	223

Figure 1.31

Age Differentiation - Acute sinusitis

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	0	0	50	0	0	50	0	0	0	2
1957	0	0	0	0	25	25	25	0	25	4
1958	0	0	0	50	0	0	0	0	50	2
1959	0	0	0	0	33	33	17	17	0	6
1960	0	0	0	33	0	0	0	67	0	3
1961	0	0	0	0	0	100	0	0	0	1
1962										
1963	5	0	10	15	30	20	10	0	10	20
1964	0	6	0	13	13	38	13	16	3	32
1965	0	9	3	3	30	24	9	9	12	33
1966	8	4	4	4	38	17	12	8	4	24
1967	0	5	0	15	15	30	20	10	5	20
1968	0	0	0	5	41	18	14	18	5	22
1969	0	8	5	5	32	26	11	11	3	38
1970	0	21	7	7	29	11	11	14	0	28
1971	33	27	8	6	15	4	0	6	0	48
TOTAL	7	10	5	8	25	20	10	11	5	283

Figure 1.32

Age Differentiation - Chronic Sinusitis

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF CASES
1956	40	17	3	5	22	2	7	2	3	60
1957	46	11	5	11	8	8	3	5	2	87
1958	37	8	3	18	10	9	11	3	3	79
1959	38	5	6	16	16	8	6	5	2	88
1960	33	12	9	13	12	7	4	5	4	75
1961	32	19	3	6	15	6	10	5	3	62
1962										
1963	24	10	7	17	10	22	5	2	2	41
1964	48	5	3	12	15	7	7	2	2	60
1965	27	18	8	10	20	4	10	0	2	49
1966	29	20	2	12	18	4	4	2	7	89
1967	64	8	3	8	8	6	0	0	3	36
1968	36	13	7	12	12	3	11	4	4	76
1969	49	12	1	9	10	3	6	1	7	67
1970	37	8	10	10	14	10	5	0	8	63
1971	36	9	6	6	21	9	6	0	6	33
TOTAL	38	12	5	12	14	7	6	3	4	965

Figure 1.33

Age Differentiation - Acute pharyngitis and nasopharyngitis

We shall now consider some of the factors which may affect the admission rates for respiratory illness at St. Patrick's Hospital. In preliminary visual analysis of the hospital admission data it was determined that mean annual temperature and total number of hours per year with visibility six miles or less at the Missoula County Airport due to smoke, fog, or haze appeared to be correlated with the annual total hospital admission rate for respiratory illness and to the annual rates for various specific illnesses.[3] In an attempt to more thoroughly document the relationship between hospital admission rates and temperature and reduced visibility, statistical correlations were determined. The linear least squares slope, y-intercept, correlation coefficient, and standard estimate of error were determined for the annual hospital admission rate for the various respiratory illnesses versus mean annual temperature and number of hours per year with visibility six miles or less due to smoke, fog, or haze. The linear least squares calculation determines the best straight line through a series of points. The least squares slope and y-intercept give the equation for that line. The correlation coefficient gives a measure of the "randomness" of the points about the least squares line. The correlation coefficient ranges in value from -1 to 1. A correlation coefficient of -1 indicates a negative linear relationship while a correlation coefficient of +1 indicates a positive linear relationship. A correlation coefficient near zero indicates that there is no simple linear functional relationship between the plotted variables. A high correlation coefficient does not imply a causal relationship between the variables, however. The relationship is mathematical and a high correlation coefficient indicates that the variables are "associated."

Figure 1.34 gives the correlation coefficients for the annual admission totals of the various respiratory illnesses versus temperature and visibility. The correlation coefficient for temperature versus visibility is also given. We can see that there is a strong negative correlation between the mean annual temperature and the annual hospital admission rate for total respiratory illness, acute upper respiratory infection, bronchitis, pneumonia, and sinusitis. The correlation indicates that respiratory illness is definitely affected by temperature. A low (cold) mean annual temperature is reflected in a high hospital admission rate. Hospital admissions for acute upper respiratory infection also show a strong positive correlation with the number of hours per year with visibility at the Missoula County Airport reduced to six miles or less due to smoke , fog, or haze. Total respiratory illness, bronchitis, pneumonia, and sinusitis also show a lesser positive correlation with reduced visibility. In previous reports it has been shown that reduced visibility at the airport due to smoke and haze is associated with elevated particulate levels in the city.[3] Hence one can infer that high particulate air pollution levels affect the annual admission rate for acute upper respiratory infection and possibly other respiratory illnesses. A high number of hours per year with reduced visibility (high particulate levels) is reflected in a high hospital admission rate for acute upper respiratory infection. In order to show this correlation visually the annual admission rate for acute upper respiratory infection and mean annual temperature and the number of hours per year with reduced visibility are plotted on the same graphs in figures 1.35 and 1.36. The correlation coefficients for acute upper respiratory infection versus visibility and total respiratory admissions, acute upper respiratory infection, bronchitis, and pneumonia

DISEASE ADMISSION RATE	MEAN ANNUAL TEMPERATURE	HOURS PER YEAR 6 MILE VISIBILITY
TOTAL RESPIRATORY ILLNESS	-.642	.366
ASTHMA	-.114	-.377
ACUTE UPPER RESPIRATORY INFECTION	-.666	.750
BRONCHITIS	-.682	.188
PNEUMONIA	-.608	.225
EMPHYSEMA	-.123	.281
SINUSITIS	-.470	.347
ACUTE PHARYNGITIS AND NASOPHARYNGITIS	.008	-.330

Figure 1.34

Correlation Coefficients--Annual Hospital Admission rates versus mean annual temperature and six mile visibility

TEMPERATURE VERSUS VISIBILITY (Not Statistically Significant)	1956 - 1971	-.350
	1963 - 1971	-.608

Figure 1.34 A

Correlation Coefficient - Temperature Versus Visibility

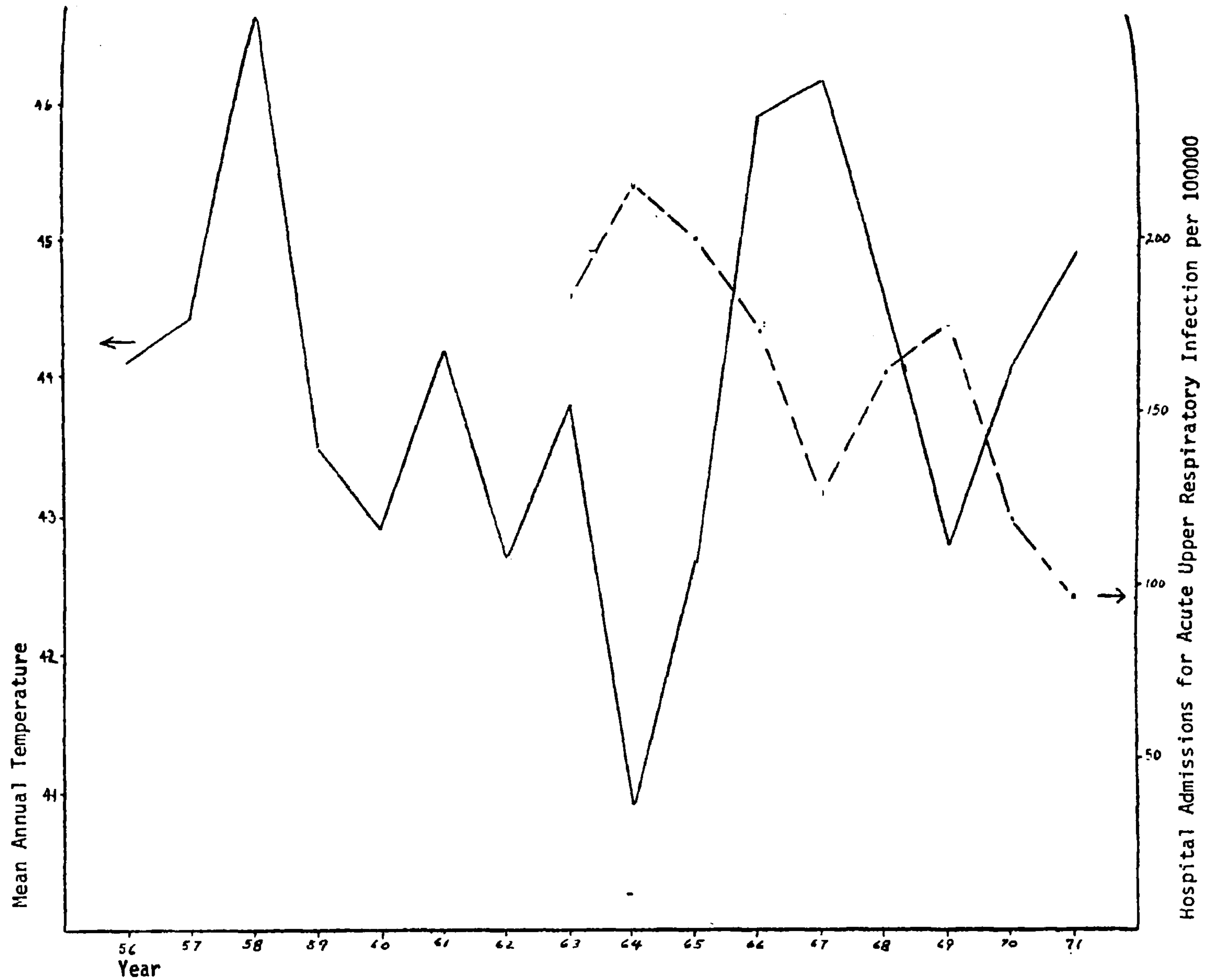


Figure 1.35

Correlation between Annual Temperature and Acute Upper Respiratory Infection

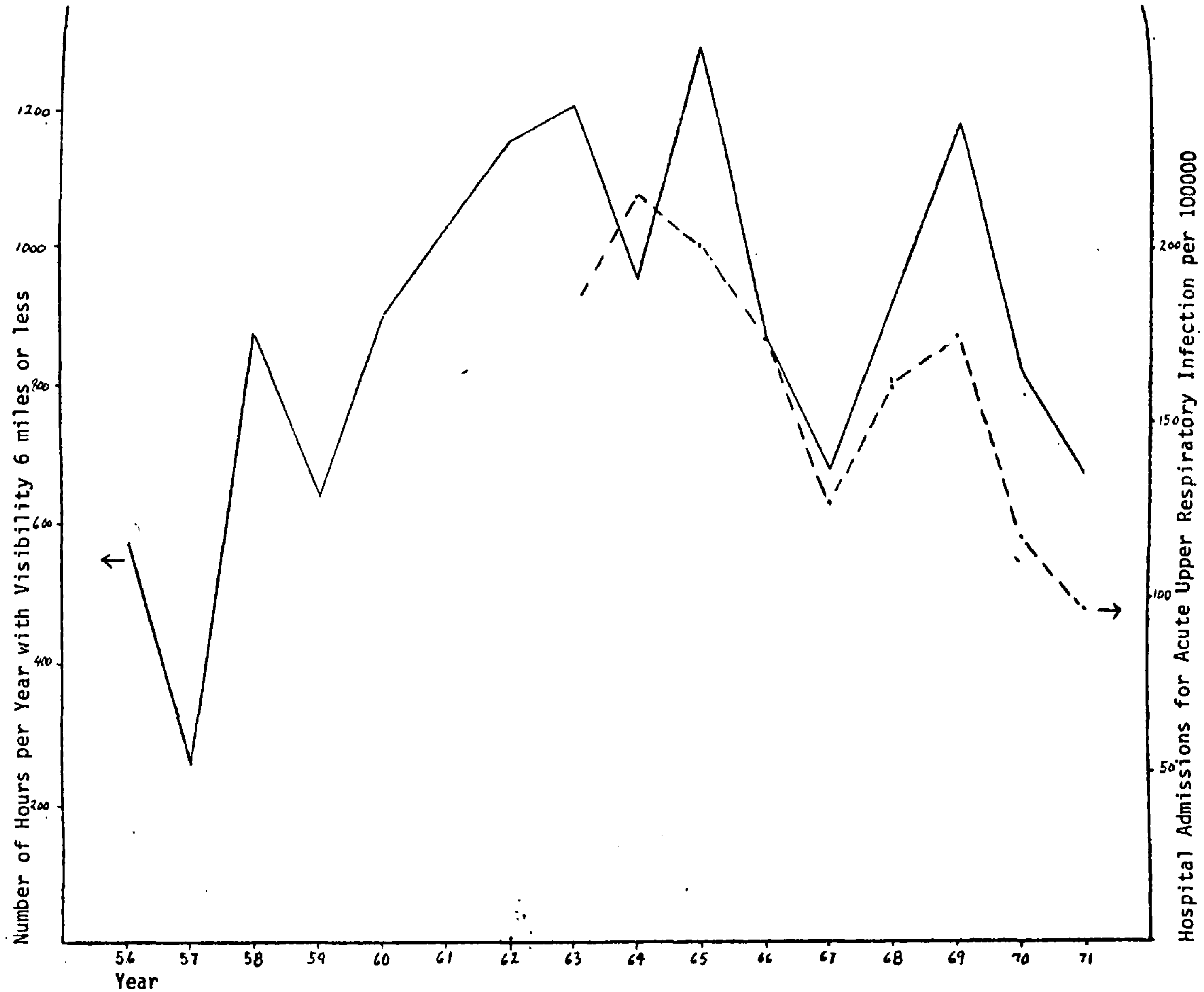


Figure 1.36

Correlation between Visibility and Acute Upper Respiratory Infection versus temperature are all significant at the .05 level This means that there is only a 5 percent chance that the correlations could have occurred through the random scattering of the data points.

The asthma, emphysema, and acute pharyngitis and nasopharyngitis annual hospital admission rates do not correlate well with either annual temperature or reduced visibility. The annual admission rates for asthma and acute pharyngitis and nasopharyngitis have decreased since 1956 while the admission rate for emphysema has increased enormously. These trends appear to have offset the effects of temperature and visibility.

In an attempt to further analyze the correlation between the annual hospital admission rate for acute upper respiratory infection and mean annual temperature and reduced visibility, multiple and partial correlation were applied to the variables. Partial correlation, applied to three variables, is a technique for finding the relationship between any two variables while removing the effect of the third variable. We have calculated the partial correlation coefficients for hospital admissions for acute upper respiratory infection versus mean annual temperature, with reduced visibility " partialed" out and for hospital admissions for acute upper respiratory infection versus reduced visibility with temperature"partialed" out. Multiple correlation, applied to three variables is a technique for determining the combined effect of two variables on a third. Multiple correlation was applied to hospital admissions for acute upper respiratory infection versus temperature and reduced visibility. These correlation coefficients are all shown in figure 1.37.

Since the hospital admission rate for acute upper respiratory infection correlates well with temperature and reduced visibility, we expanded our analysis of this particular illness to include monthly hospital admissions and various other environmental parameters. Linear least squares analysis was applied to the monthly hospital admission rate for acute upper respiratory infection versus monthly inversion index, number of hours per month with visibility six miles or less due to smoke, fog, or haze, average monthly departure from normal temperature, mean monthly temperature, total monthly precipitation, average monthly relative humidity at 11a.m. monthly average percent of possible sunshine, and average monthly particulate.[4] The correlation coefficients for monthly hospital admissions for acute upper respiratory infection versus the various environmental parameters are given in figure 1.38. We observe that the monthly hospital admission rate for acute upper respiratory infection is positively correlated with the monthly inversion index, number of hours per month with visibility six miles or less, average monthly relative humidity, and average monthly particulate level. The admission rate is negatively correlated with departure from normal temperature, average monthly temperature, and average percent of possible sunshine. The highest correlation was between the monthly admission rate for acute upper respiratory infection and the average monthly particulate level, with the negative correlation between temperature and acute upper respiratory infection ranking second. In general the correlation coefficients for monthly rates of acute upper respiratory infection are less than the correlation coefficients for the annual totals. In our analysis of the data it appeared that " lag times" were evident, particularly with temperature and visibility reduction. The months following low temperature and poor visibility months often had high rates of acute upper respiratory infection.

PARTIAL CORRELATION

Acute Upper Respiratory Infection versus mean annual temperature	-.399
Acute Upper Respiratory Infection versus reduced visibility	.583

MULTIPLE CORRELATION

Acute Upper Respiratory Infection versus temperature and visibility	.797

Figure 1.37

Partial and Multiple Correlation -- Acute Upper Respiratory Infection versus Temperature and Reduced Visibility.

VARIABLE	CORRELATION COEFFICIENT
MONTHLY INVERSION INDEX	.266
HOURS PER MONTH WITH VISIBILITY 6 MILES OR LESS	.235
AVERAGE MONTHLY DEPARTURE FROM NORMAL TEMPERATURE	-.128
AVERAGE MONTHLY TEMPERATURE	-.419
AVERAGE MONTHLY PRECIPITATION	.016
AVERAGE MONTHLY RELATIVE HUMIDITY 1100M	.364
AVERAGE MONTHLY PERCENT OF POSSIBLE SUNSHINE	-.278
AVERAGE MONTHLY PARTICULATE	.489

Figure 1.38

Correlation Coefficients--Monthly Hospital Admissions for Acute Upper Respiratory Infection versus various Environmental Parameters

Statistical analysis for "lag times" will be attempted in future studies. It is quite possible, however, that"lag times" are responsible for the observed reduction in the correlation coefficient. The correlations between monthly acute upper respiratory infection and average monthly temperature and particulate are significant at the .01 level, while the correlation between monthly acute upper respiratory infection and monthly inversion index, reduced visibility, relative humidity. and percent of possible sunshine are significant at the .05 level.

Chapter Two

Respiratory Deaths in Missoula County

This chapter deals with the mortality rates for respiratory diseases, and the total mortality rate for Missoula County. The data for this portion of the study were obtained from the death indices of the Missoula County Clerk and Recorder's Office.[5] The statistical information contained in the death indices include the age, sex, address, occupation, and cause or causes of death for every death occurring in Missoula County. Many of the deaths list multiple causes. For the purposes of this study every death with a respiratory disease listed as a cause of death was included,whether the respiratory disease was the sole cause of death or not.

Five categories of respiratory diseases were chosen to be studied. They are: 1) pneumonia (excluding hypostatic pneumonia), 2) bronchitis-bronchiolitis, 3) emphysema, 4) asthma, 5) upper respiratory infection. Each disease was then divided into totals by month, and year from 1950 to 1971, and the totals converted to deaths per 100,000. Combined respiratory deaths (the five categories), and deaths from all causes were totaled and converted in the same manner Of these totals, bronchitis-bronchiolitis, and upper respiratory infection proved to be numerically insignificant, and were not categorized further.

The annual combined respiratory death rate shows a sharp increase during the twentytwo year period, as indicated in figure 2.1. Monthly totals for this category are shown in figures 2.2 - 2.23. Death from all causes is shown by the solid line in figure 2.24, while the dashed line indicates the National average.[6] The total death rate for Missoula County is essentially constant.

The asthma, emphysema, and pneumonia death rates (solid lines) are plotted against the National average (dashed line) in figures 2.25 - 2.27. Monthly totals for pneumonia deaths are shown in figures 2.28 - 2.49. The emphysema and asthma death rates both show slight increases over the National average. (The National average for emphysema was not available from 1950 to 1960.) Pneumonia shows a very sharp increase during the twentytwo year period, and is far above the National average. The increase in the pneumonia death rate is responsible for most of the increase noted in the combined respiratory death rate. Many of the pneumonia deaths had more than one contributing cause listed in the death indices. The percentage of pneumonia deaths with multiple causes listed is shown in figure 2.50.

Pneumonia, asthma, emphysema, and combined respiratory deaths were also divided into age group and sex categories. Sex differentiation is indicated in figures 2.51 - 2.54. Females are represented by the dark portion of the column, and males by the lighter portion. The percentage of male deaths is higher in every category, with emphysema being the most striking example.

Age group differentiation is shown in figures 2.55 - 2.58. In every category the largest percentage of deaths is in the 70+ age group, with pneumonia, emphysema, and combined respiratory deaths over 50 percent, and asthma at 45 percent. The 60 69, 50 - 59, and 0 - 4 age groups also indicate fairly large percentages.

Determination of residence was also made for combined respiratory deaths from 1950 to 1971. Some of the deaths listed in the Missoula County death indices were of individuals who were not Missoula County residents. This differentiation is shown in figure 2.59. The dark portion of the column indicates those who resided outside Missoula County, while the light portion represents Missoula County residents. In every year, at least 70 percent, but usually more, of the deaths were of those who resided in Missoula County. Missoula County residents comprised 82 percent of the deaths recorded in the study.

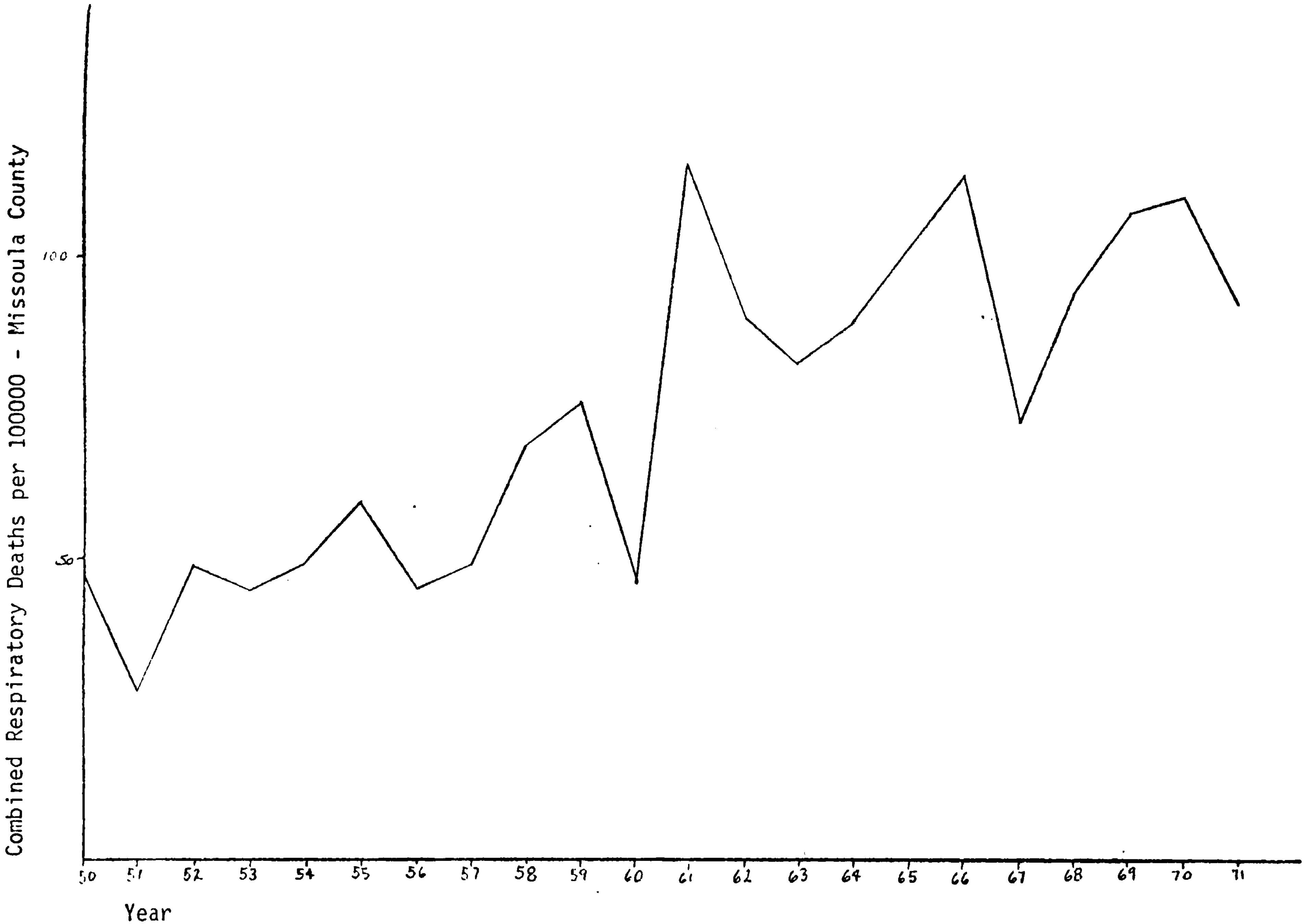
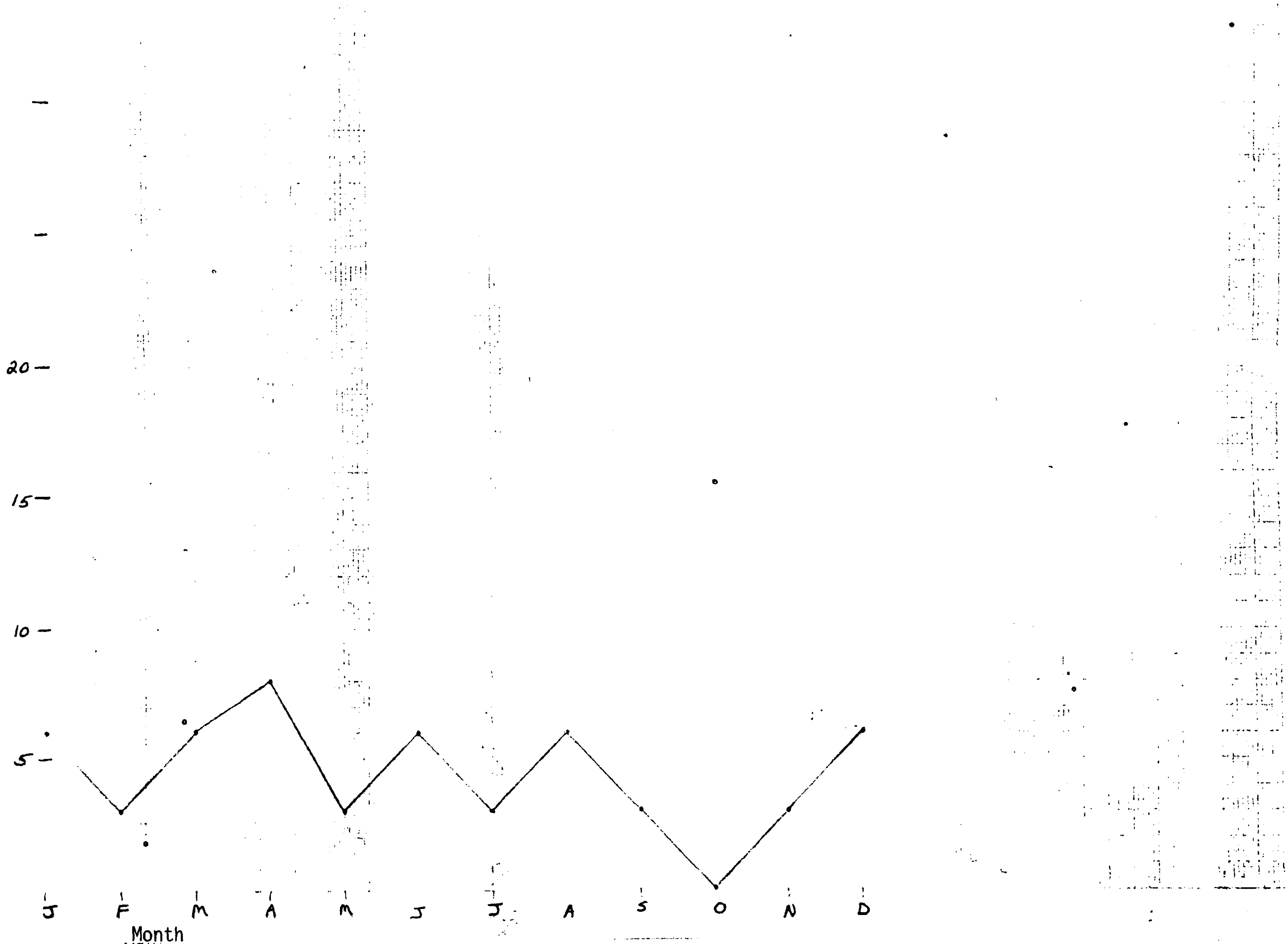


Figure 2.1

Combined Respiratory Deaths per 100000 population - Missoula County 1950 - 1971

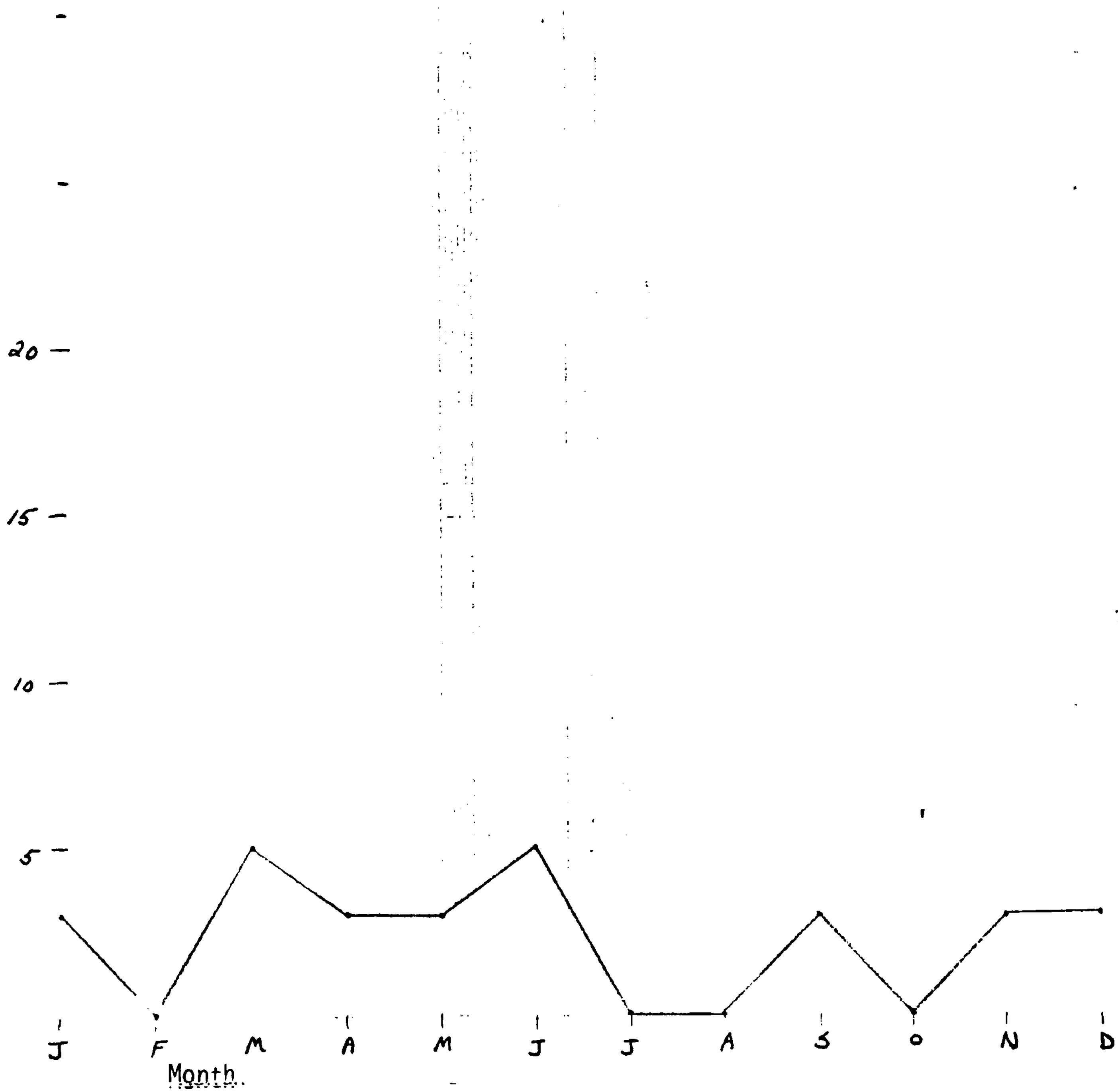
Combined respiratory deaths per 100000 -- 1950

Figure 2.2



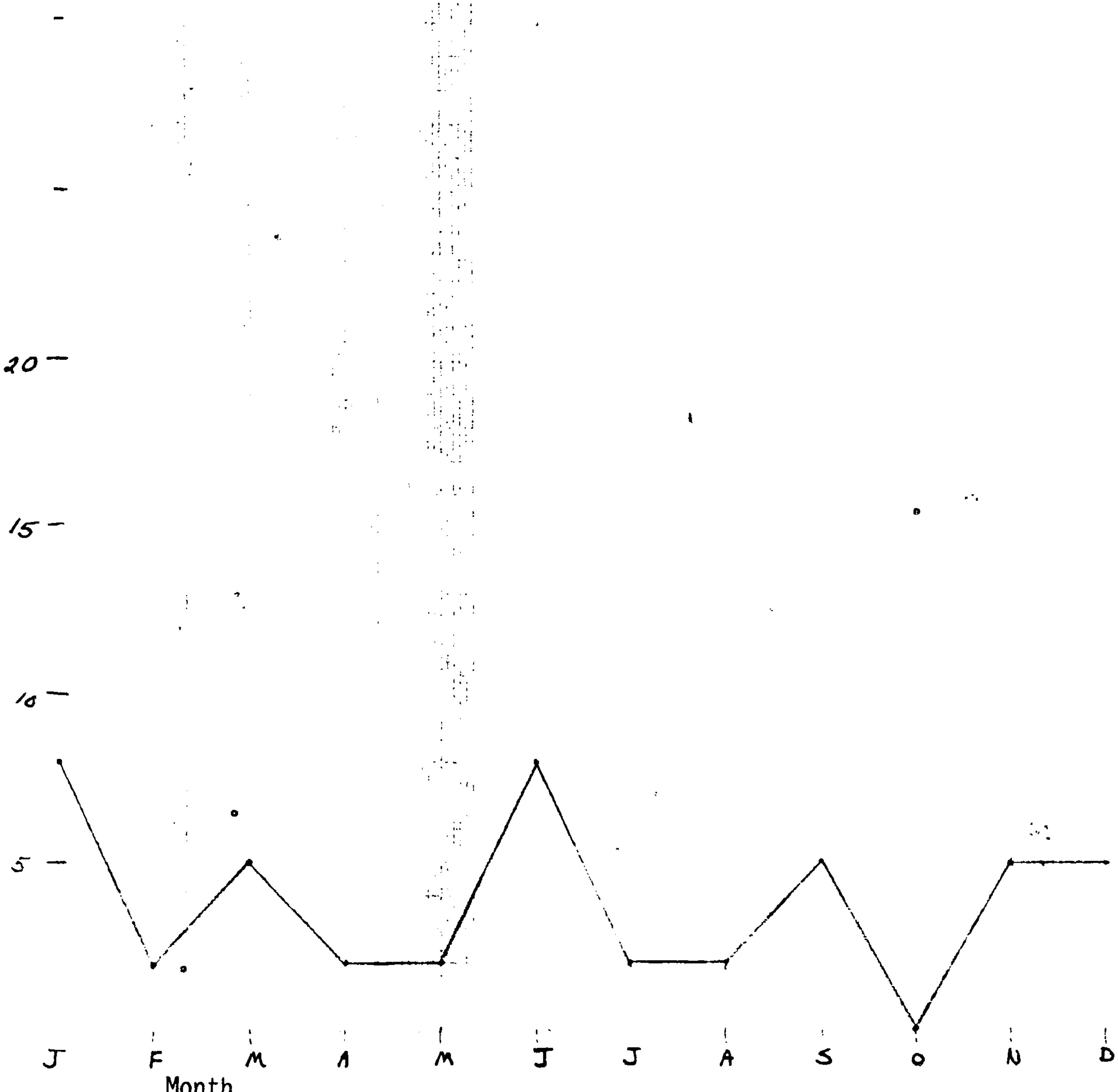
Combined respiratory deaths per 100000 -- 1951

Figure 2.3



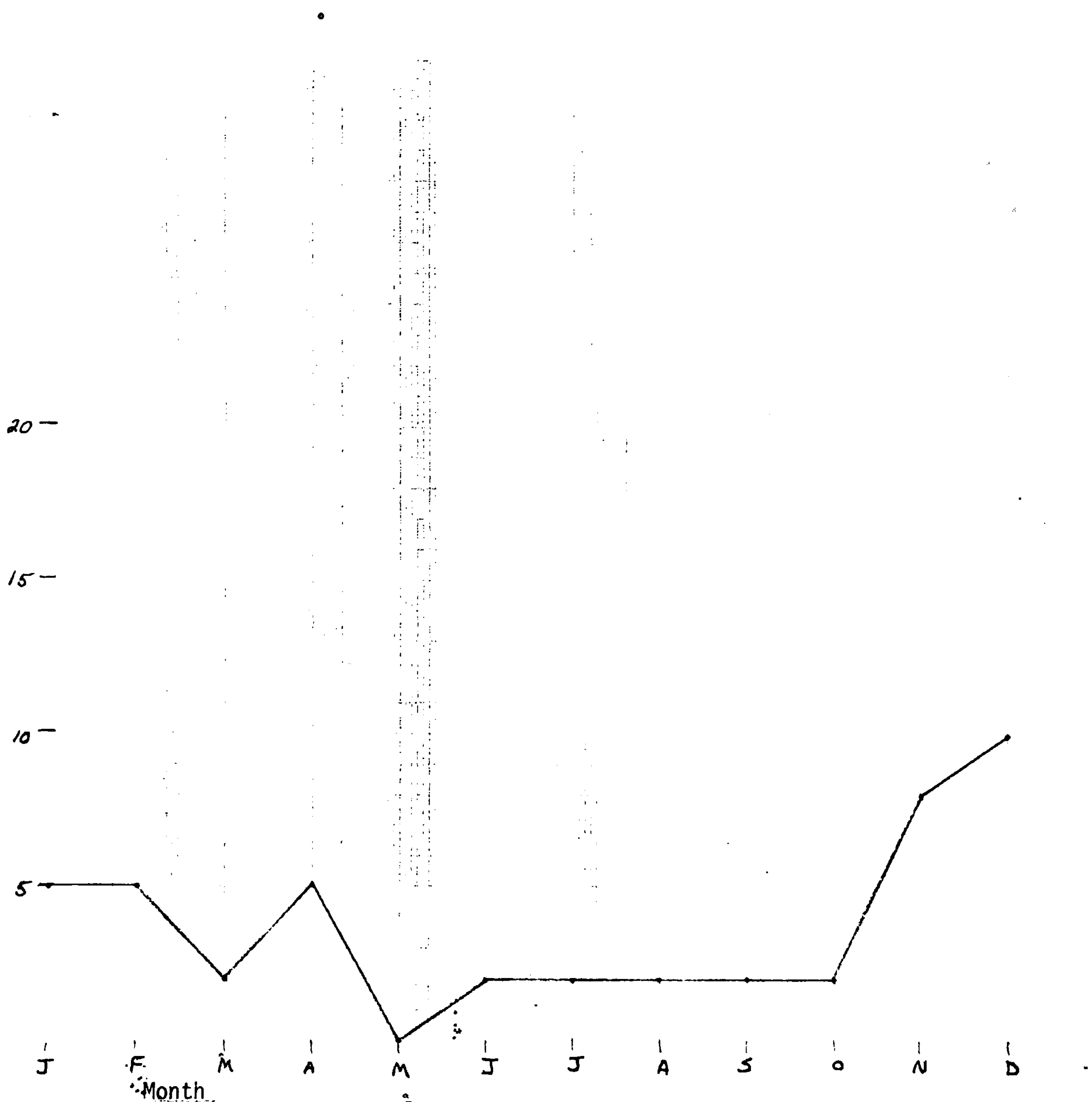
Combined respiratory deaths per 100000 -- 1952

Figure 2.4

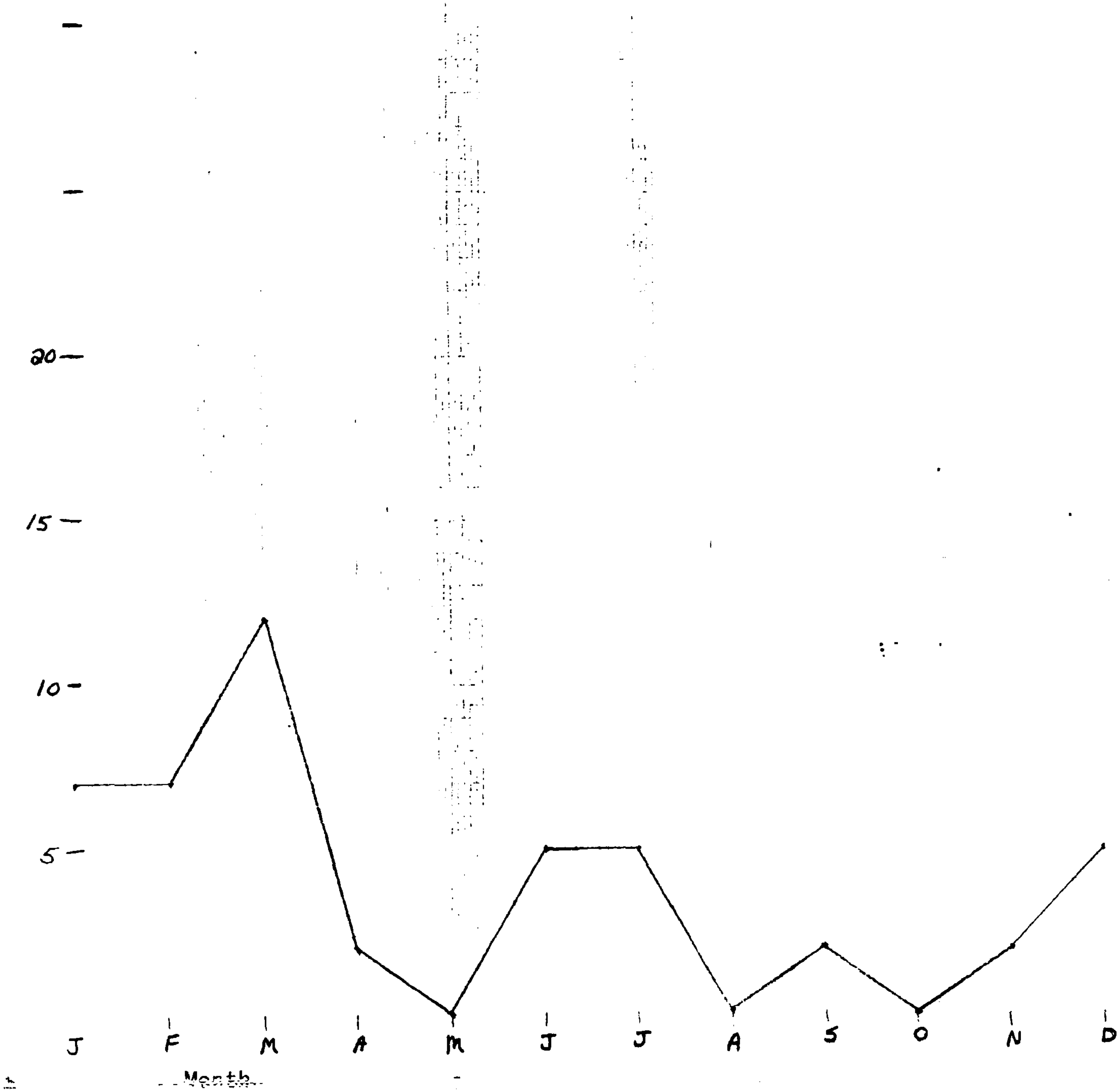


Combined respiratory deaths per 100000 -- 1953

Figure 2.5

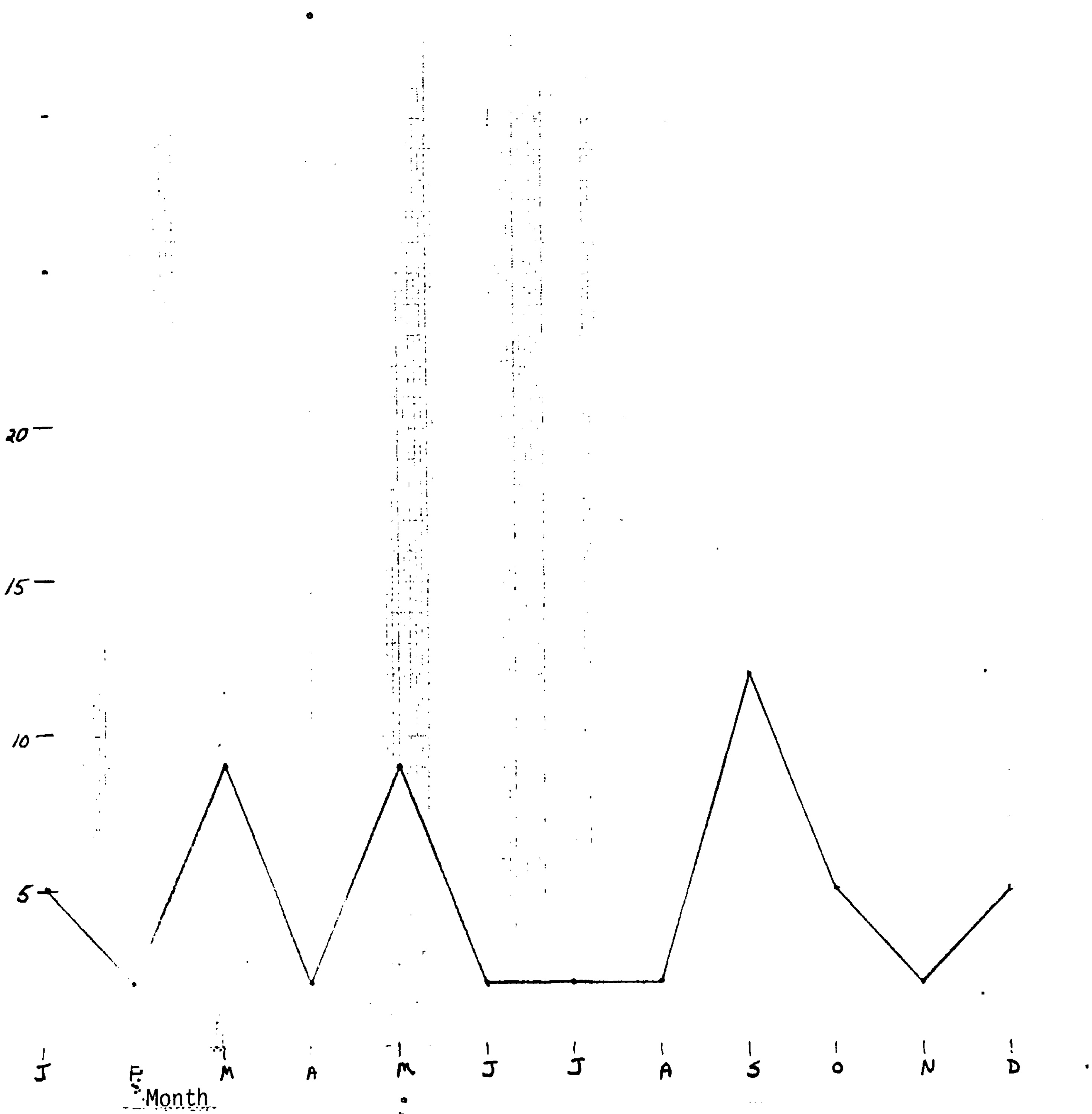


Combined Respiratory Deaths per 100000 -- 1954 Figure 2.6

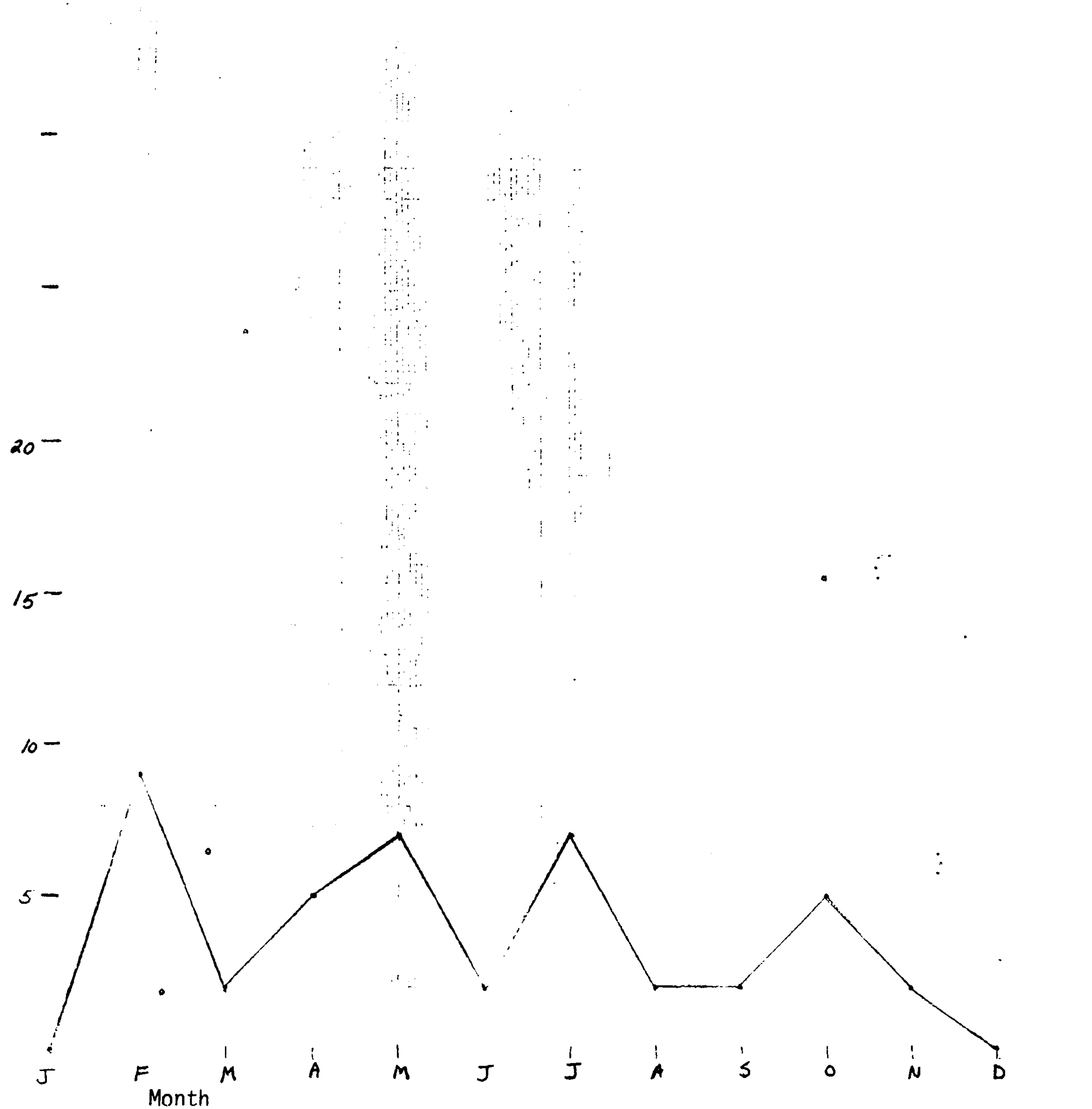


Combined respiratory deaths per 100000 -- 19[illegible]

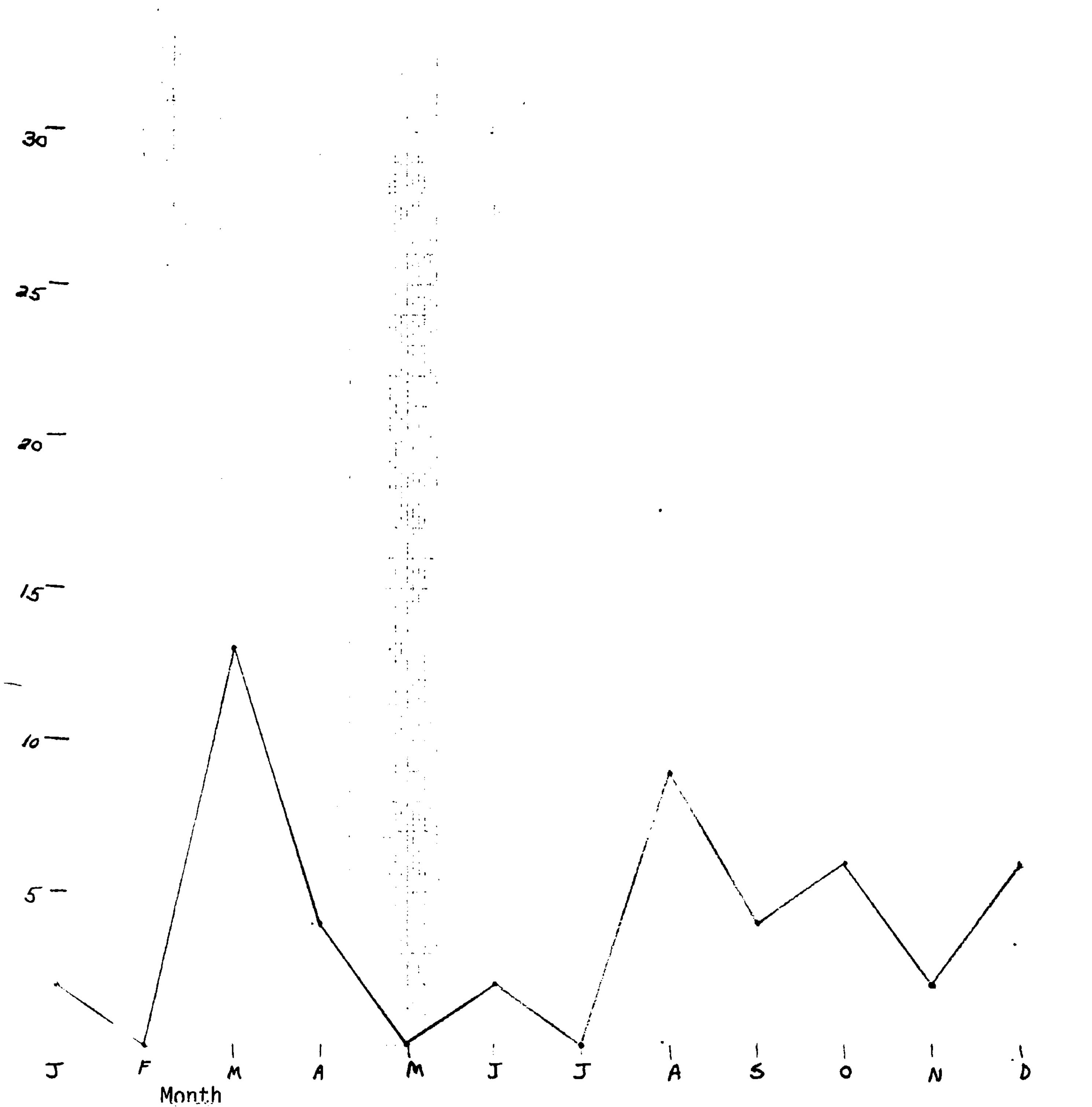
Figure [illegible]



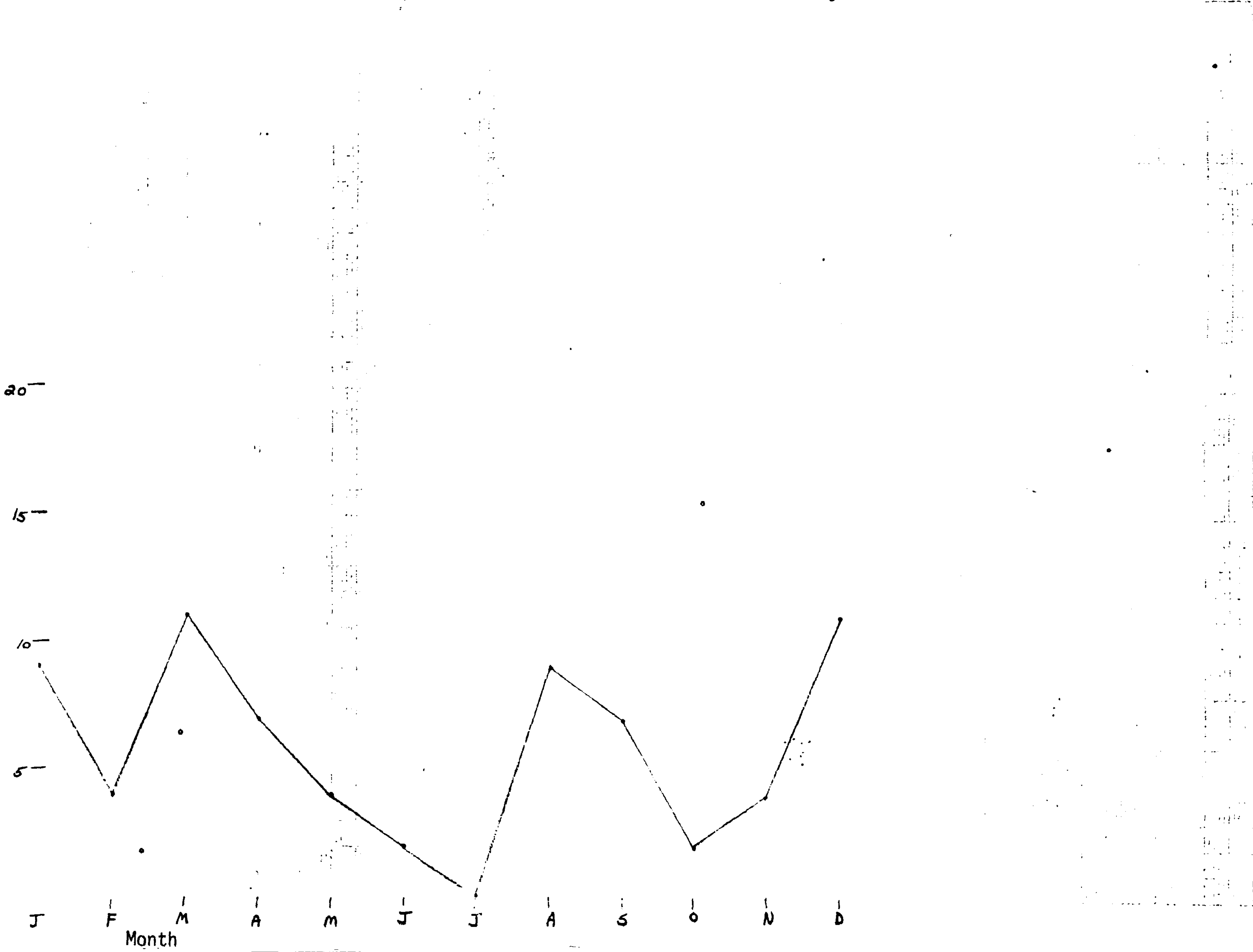
Combined Respiratory Deaths per 100000 -- 1956 Figure 2.8



Combined respiratory deaths per 100000 -- 1957 Figure 2.9

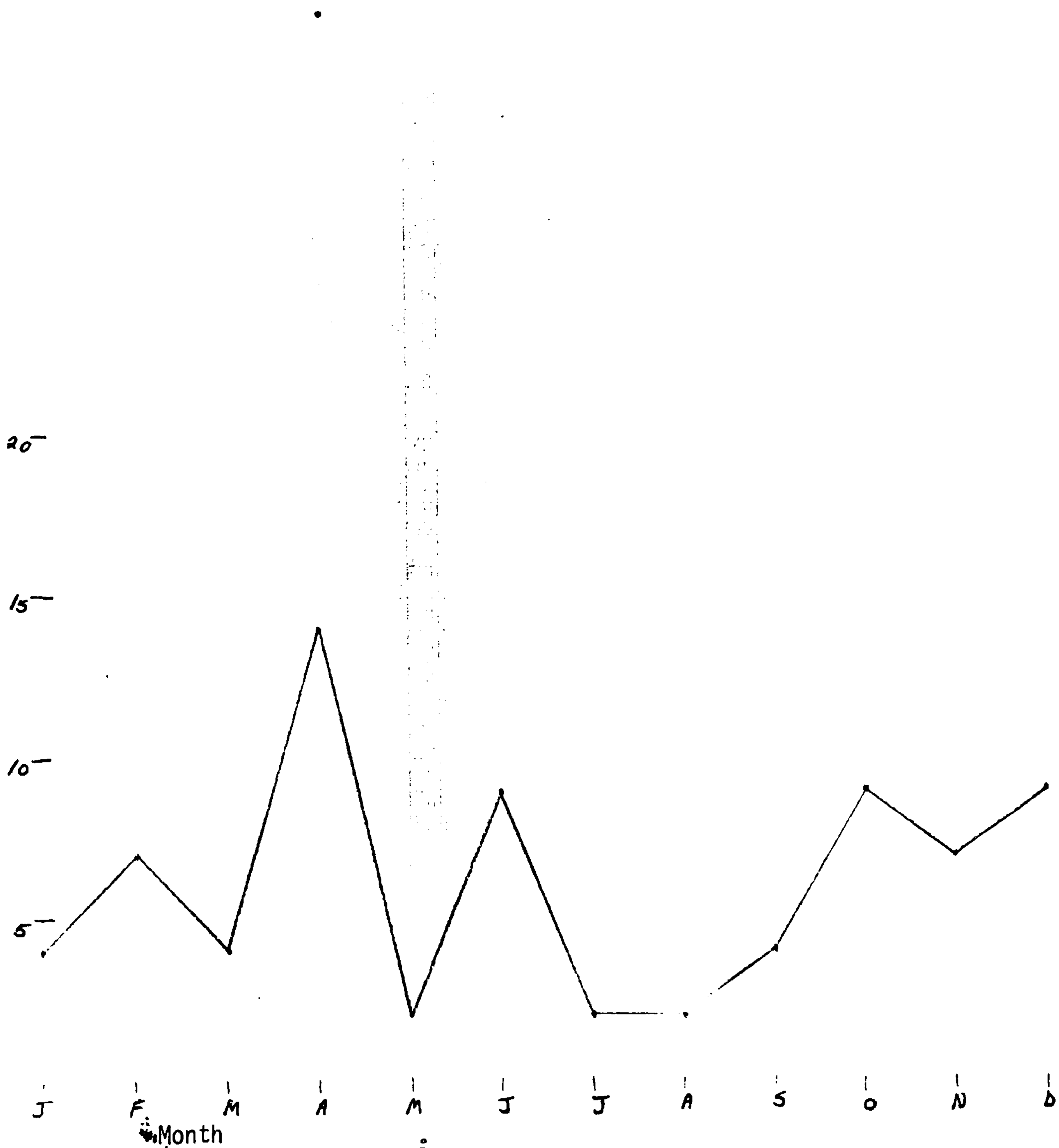


Respiratory deaths per 100000 -- 1958 Figure 2.10

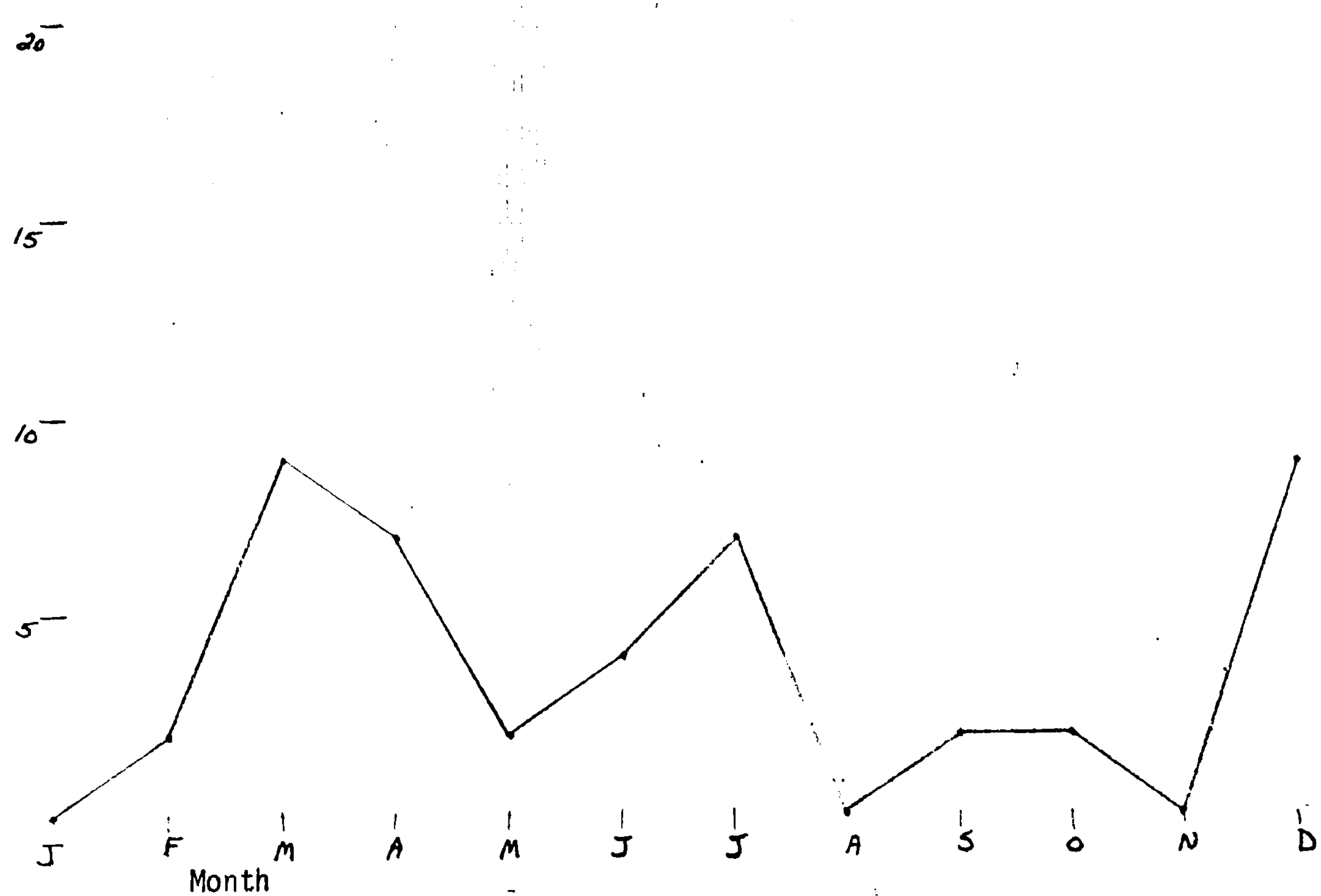


Combined Respiratory Deaths per 100000 -- 1959

Figure 2.11

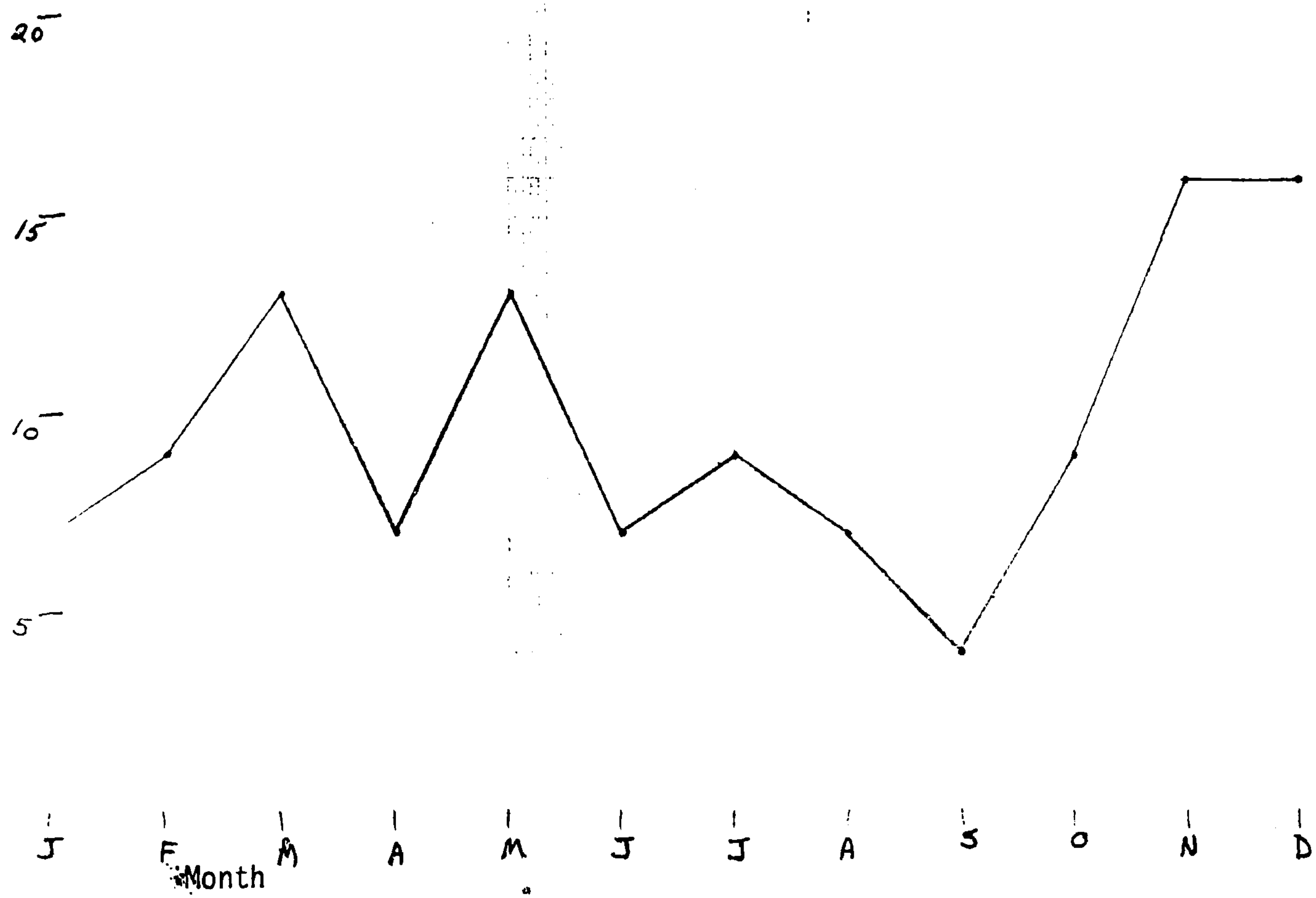


Combined Respiratory Deaths per 100000 -- 1960 Figure 2.12

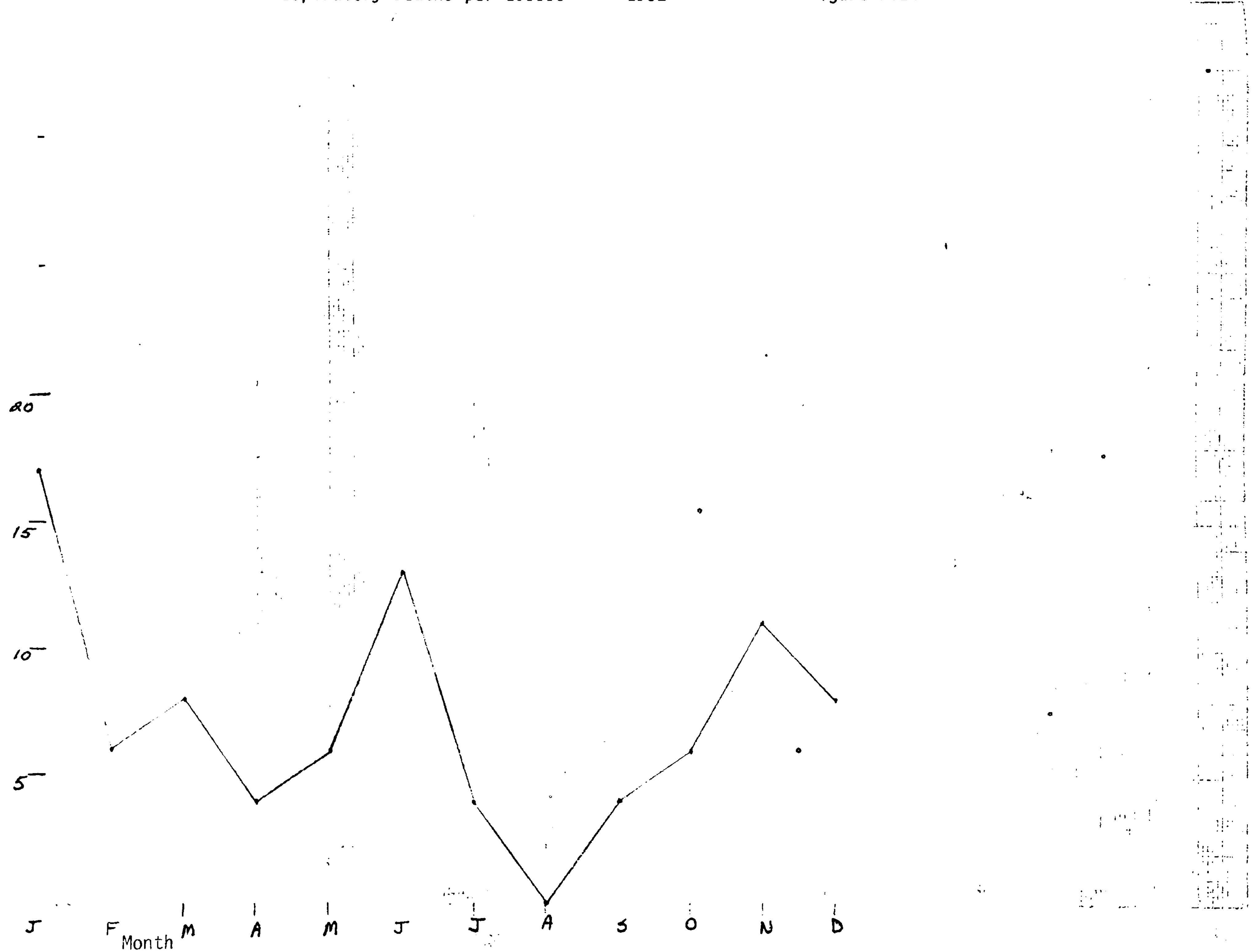


Combined Respiratory Deaths per 100000 -- 1961

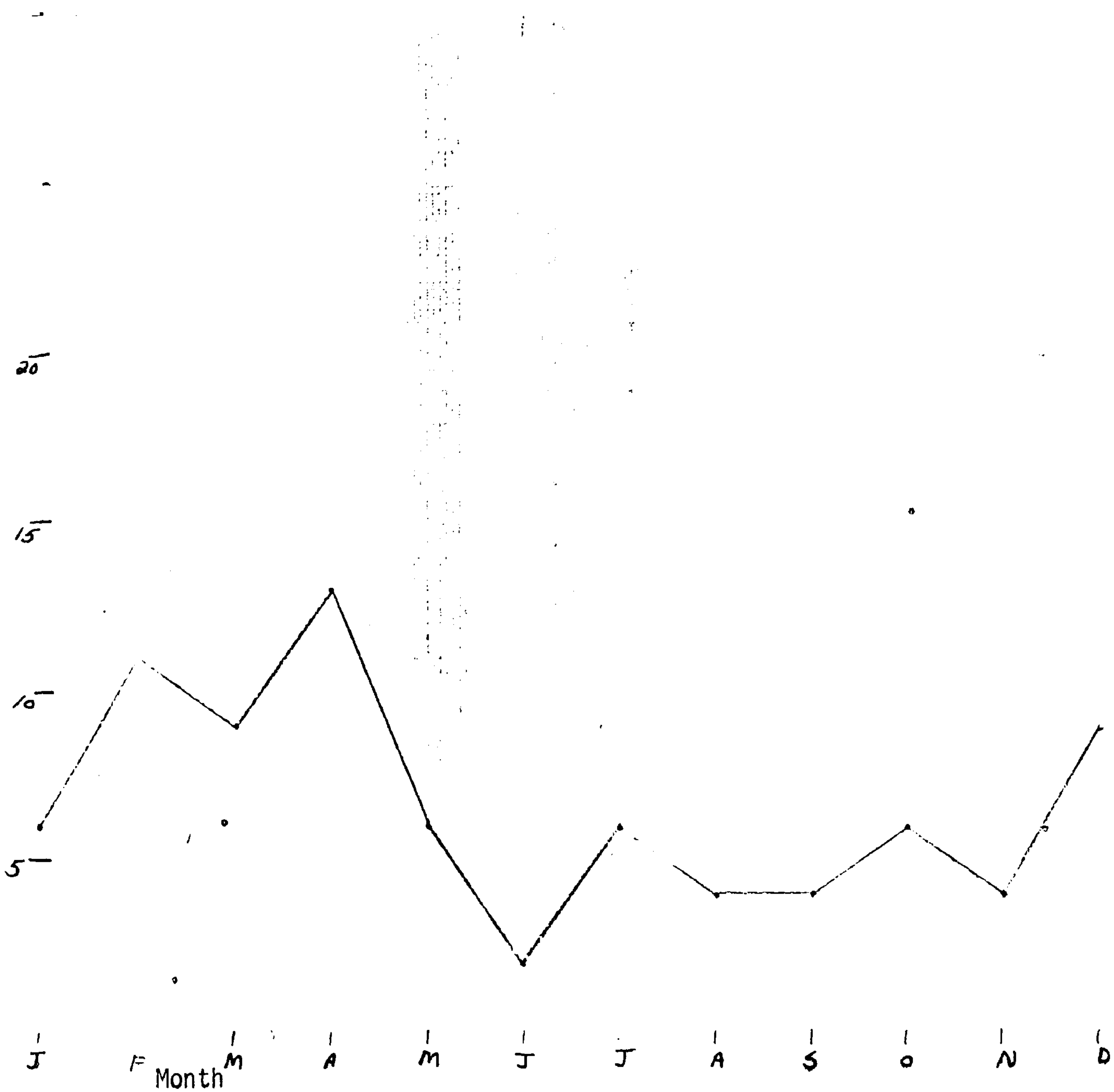
Figure 2.13



Combined Respiratory Deaths per 100000 -- 1962 Figure 2.14

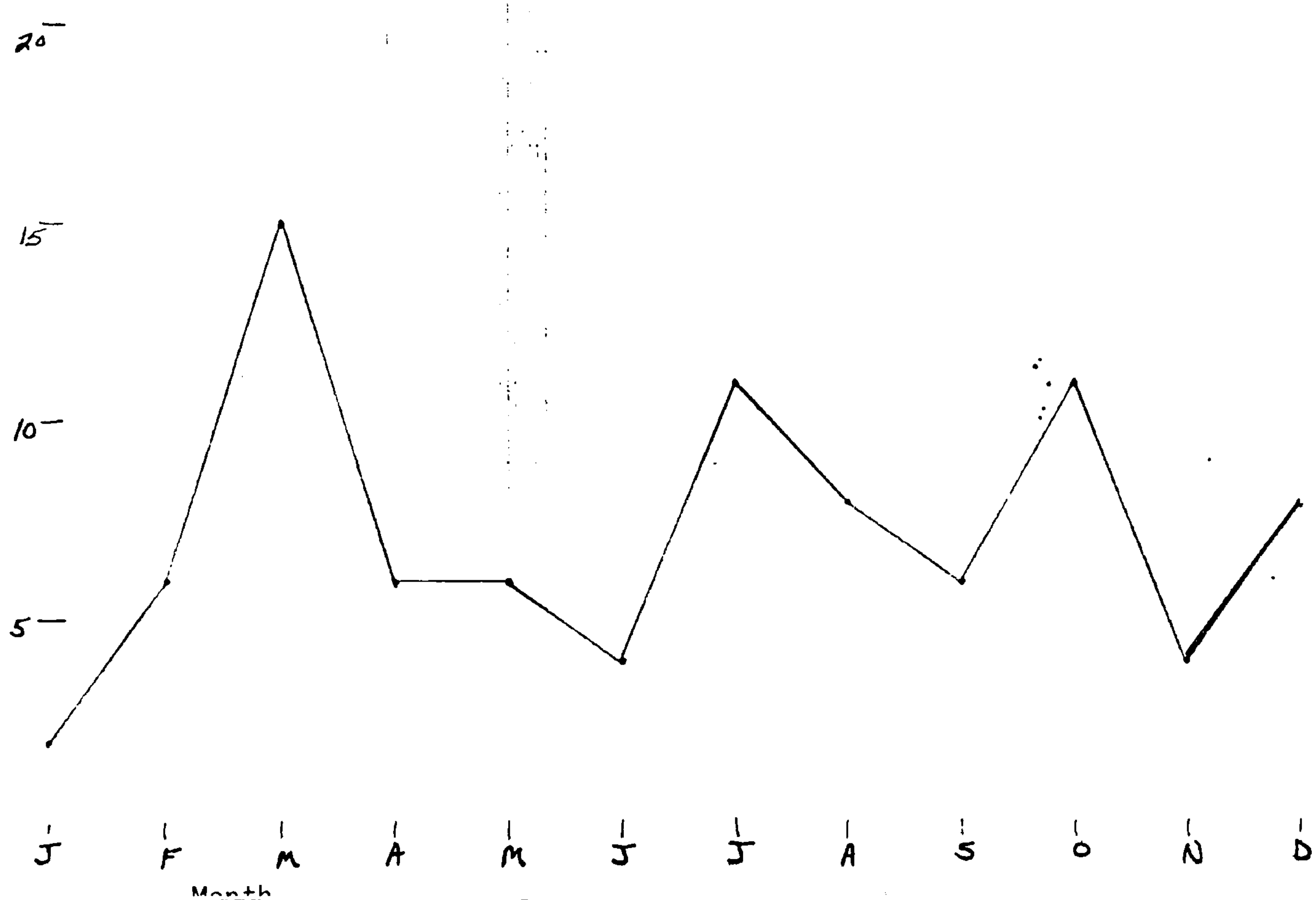


Combined Respiratory Deaths per 100000 -- 1963 Figure 2.15

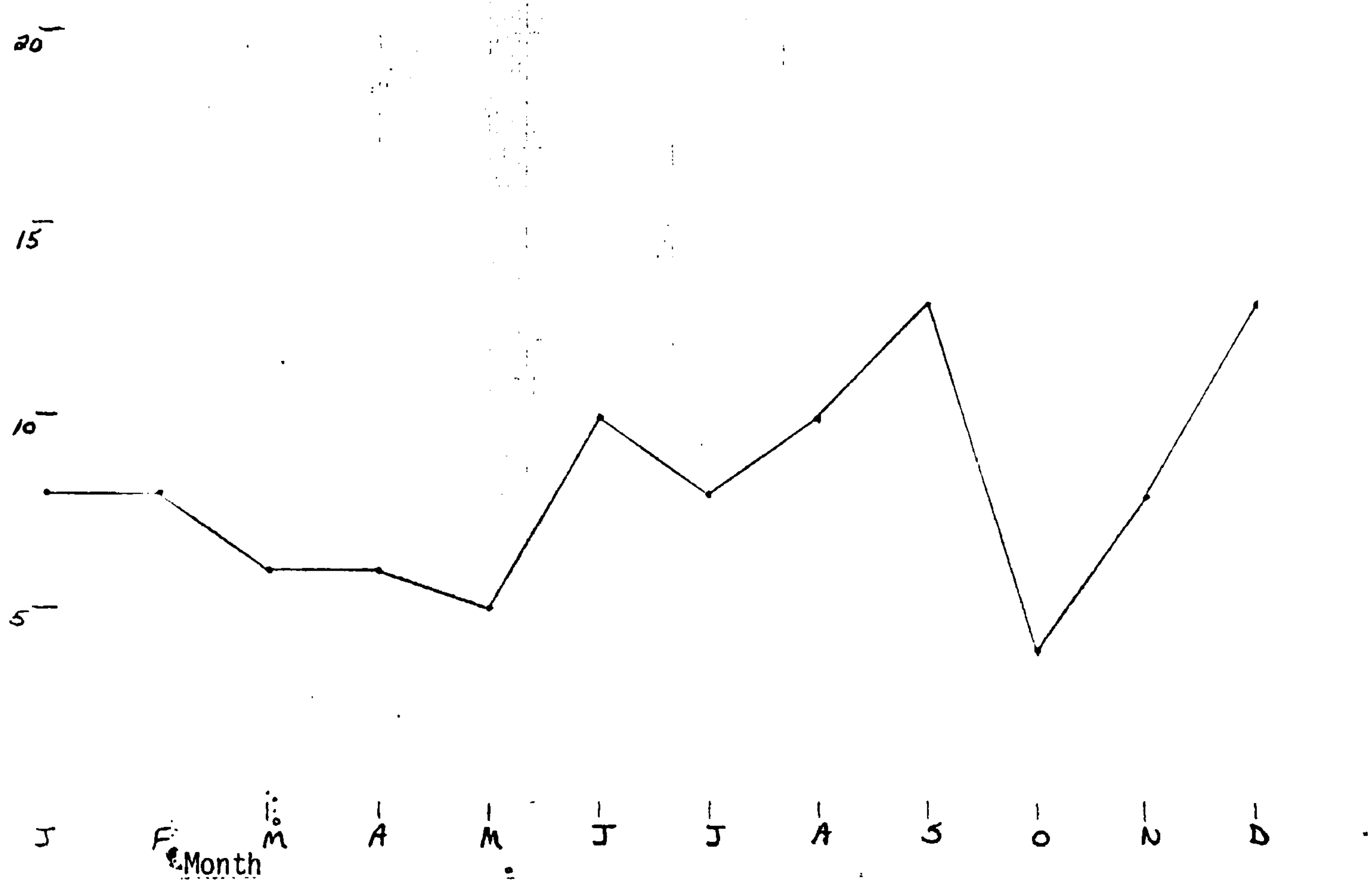


Combined respiratory deaths per 100000 -- 1964

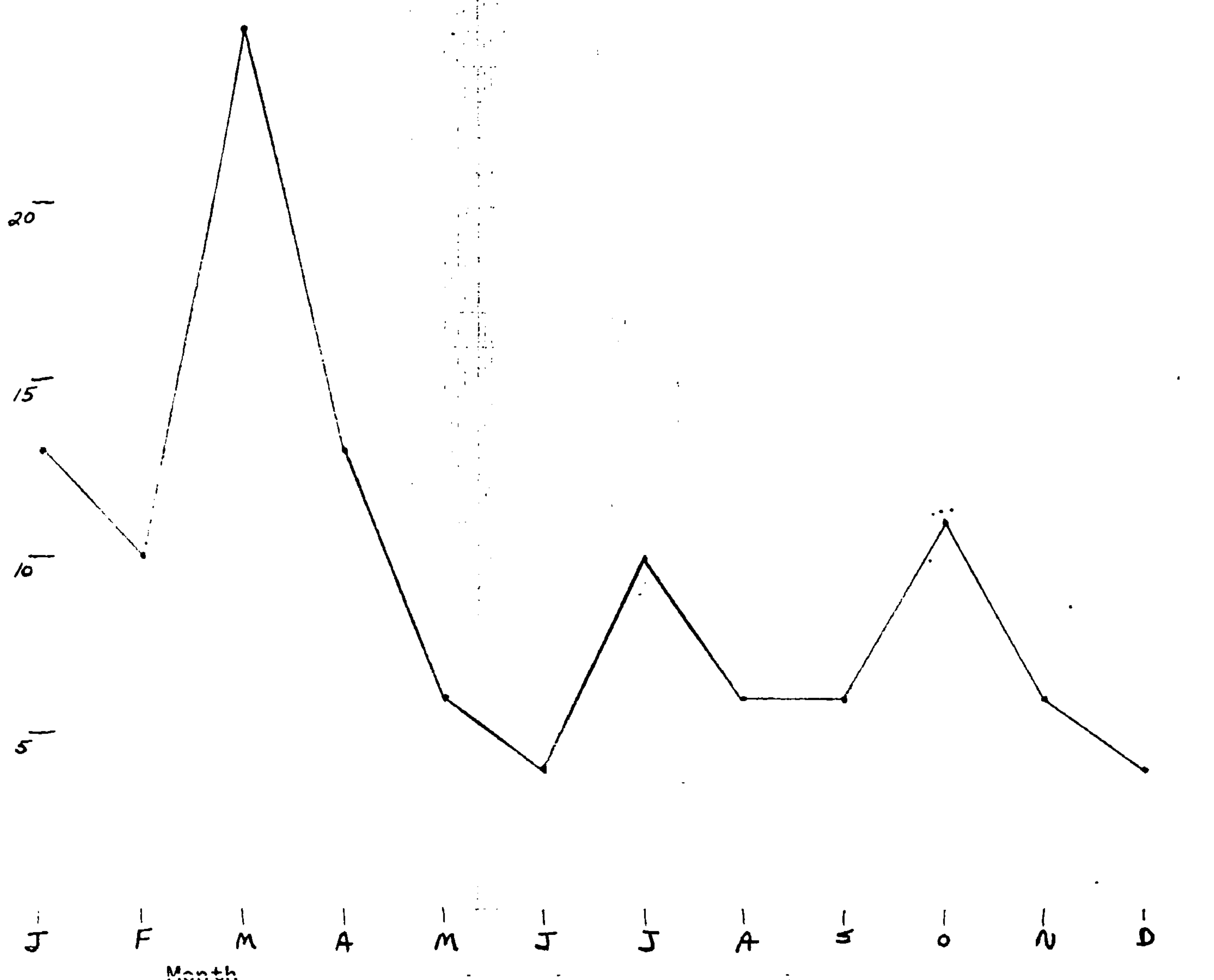
Figure 2.16



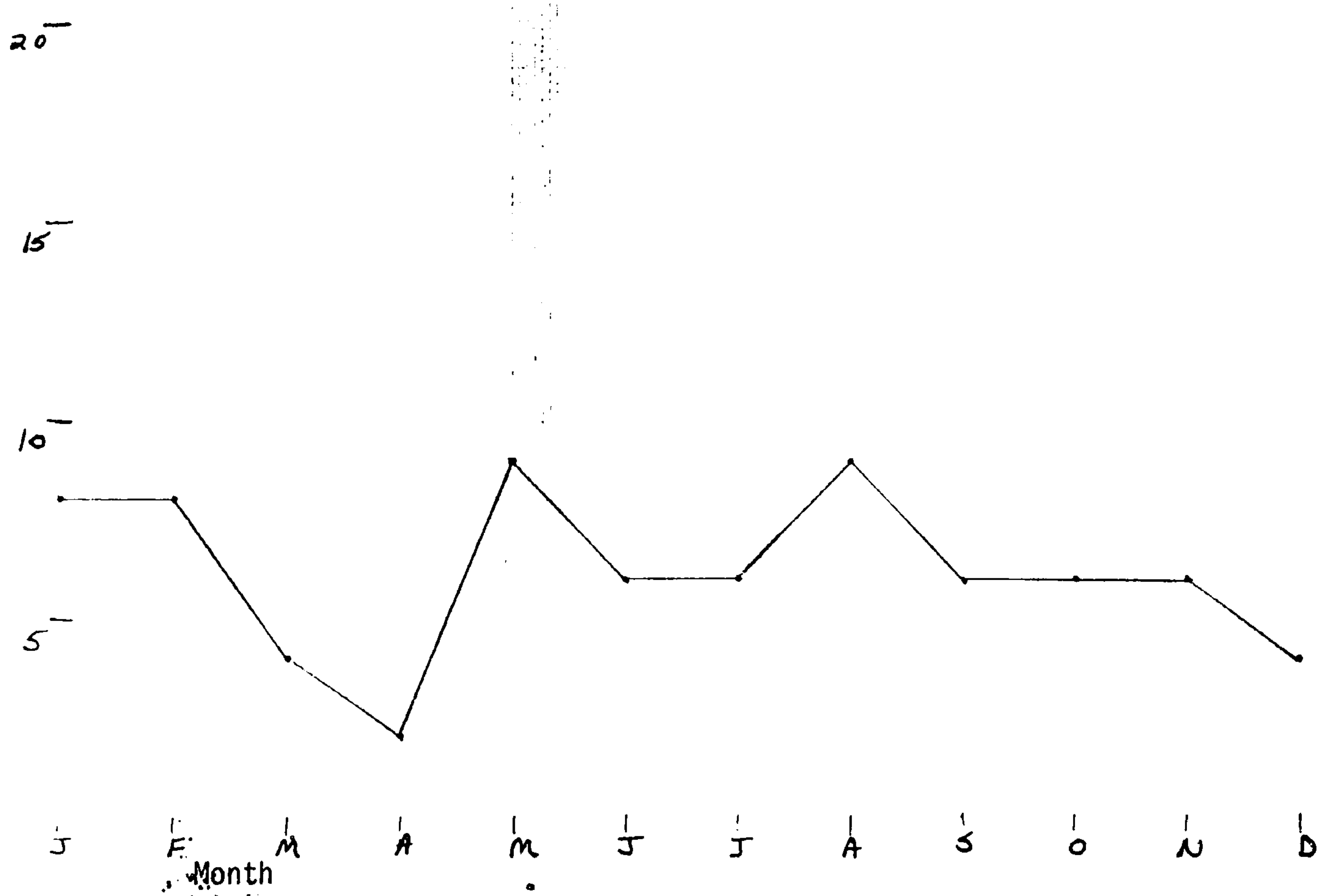
Combined respiratory deaths per 100000 -- 1965 Figure 2.17



Combined respiratory deaths per 100000 -- 1966 Figure 2.18

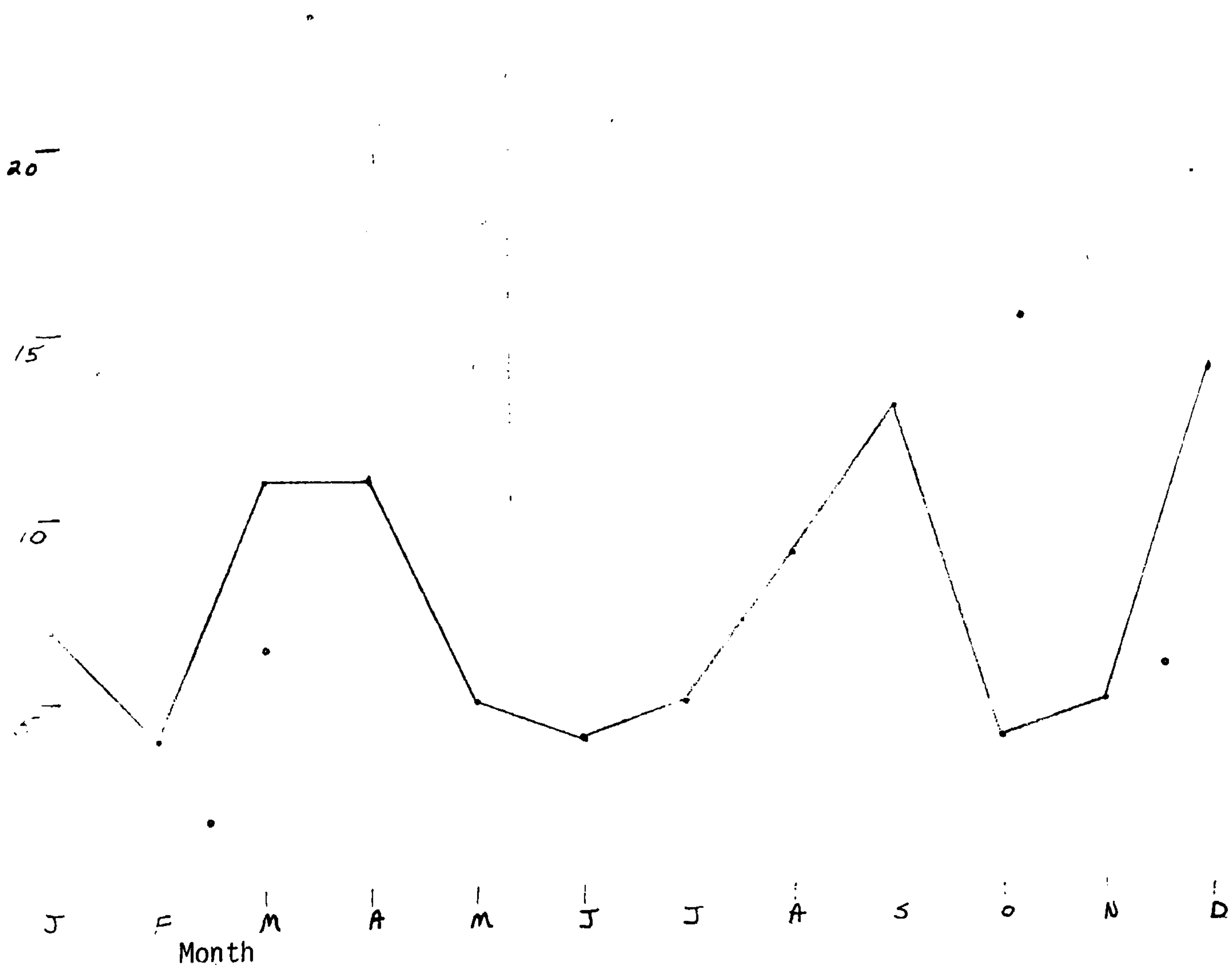


Combined Respiratory Deaths per 100000 -- 1967 Figure 2.19

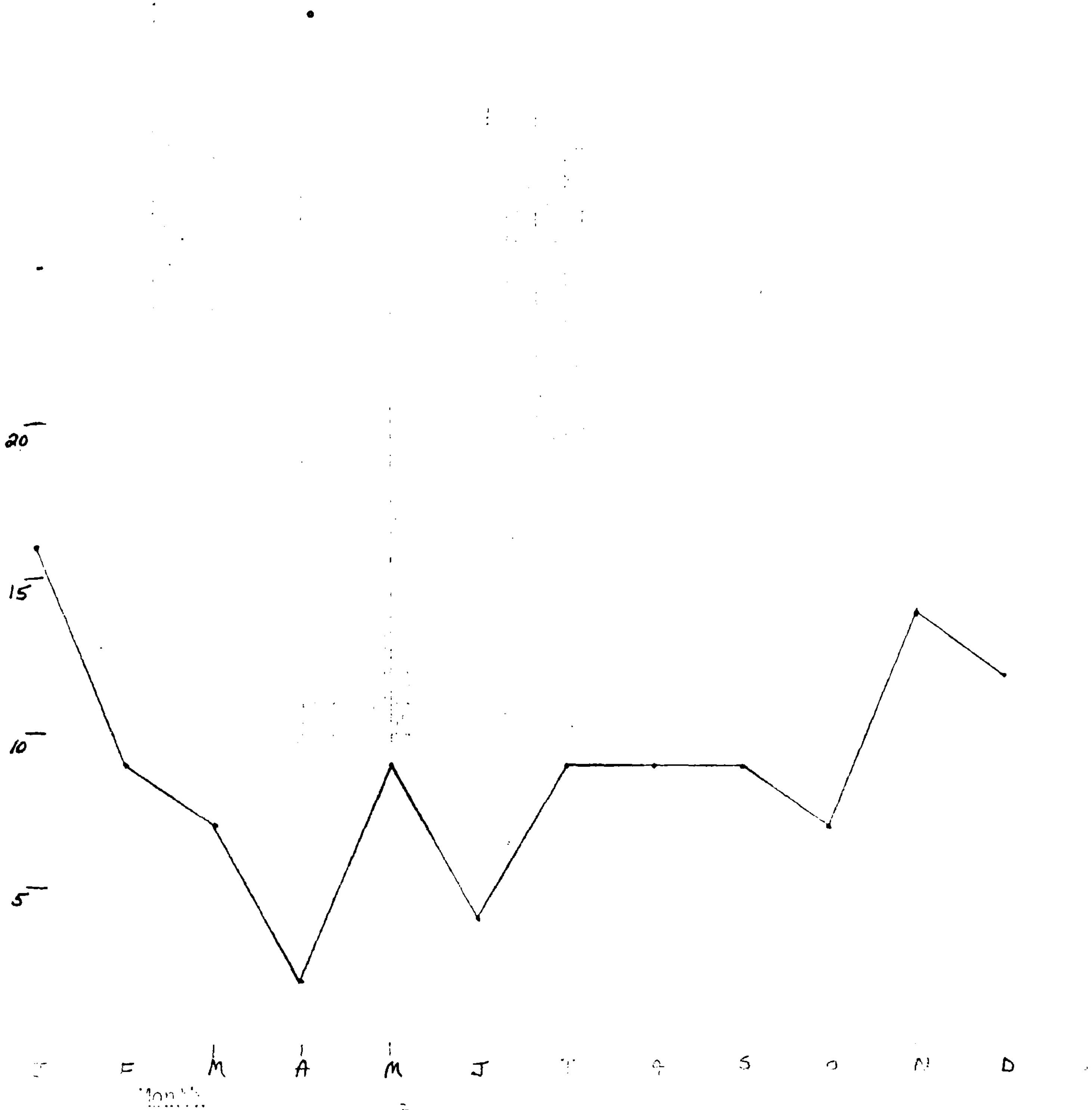


Combined respiratory deaths per 100000 -- 1968

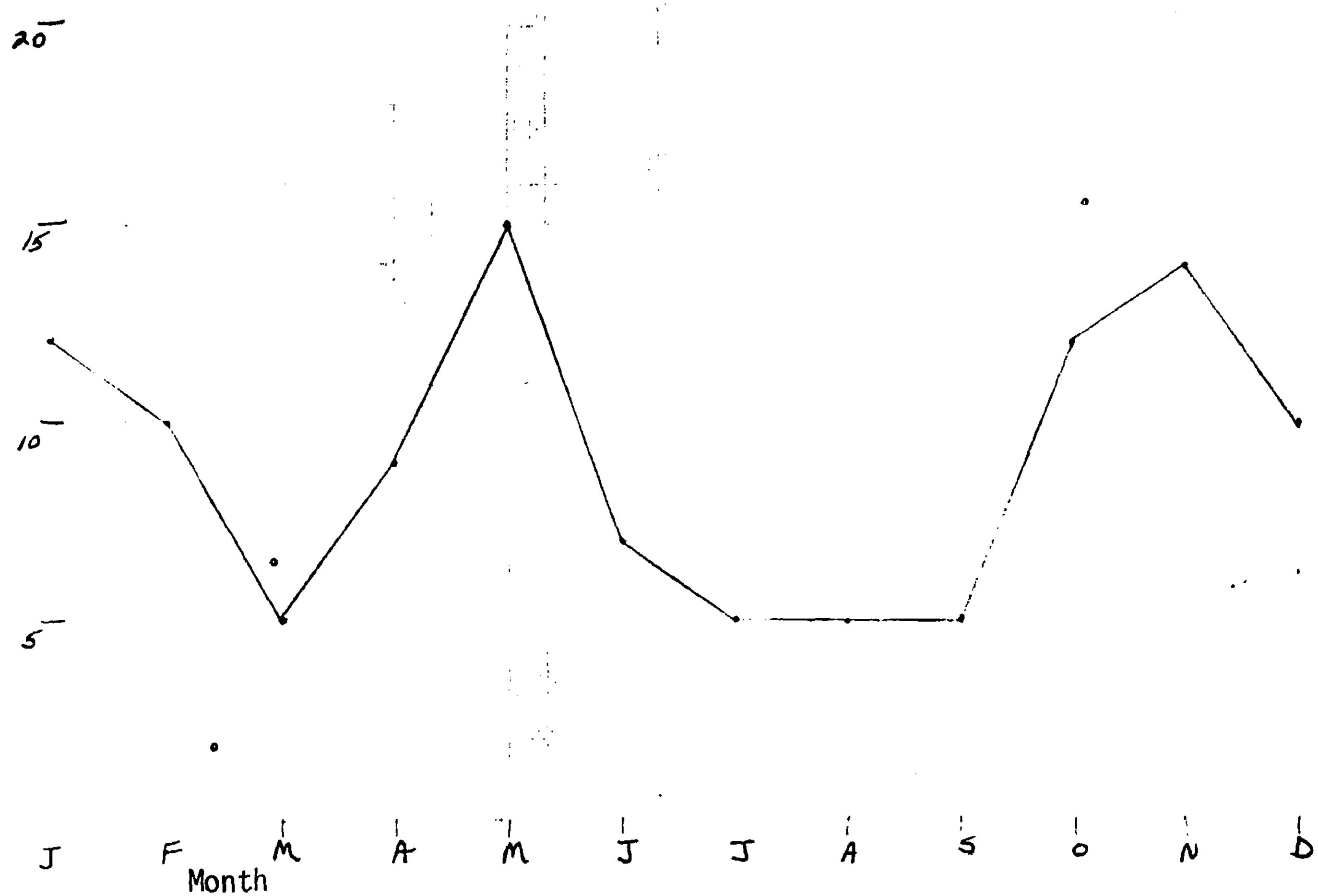
Figure 2.20



Combined respiratory deaths per 100000 -- 1969 Figure 2.21

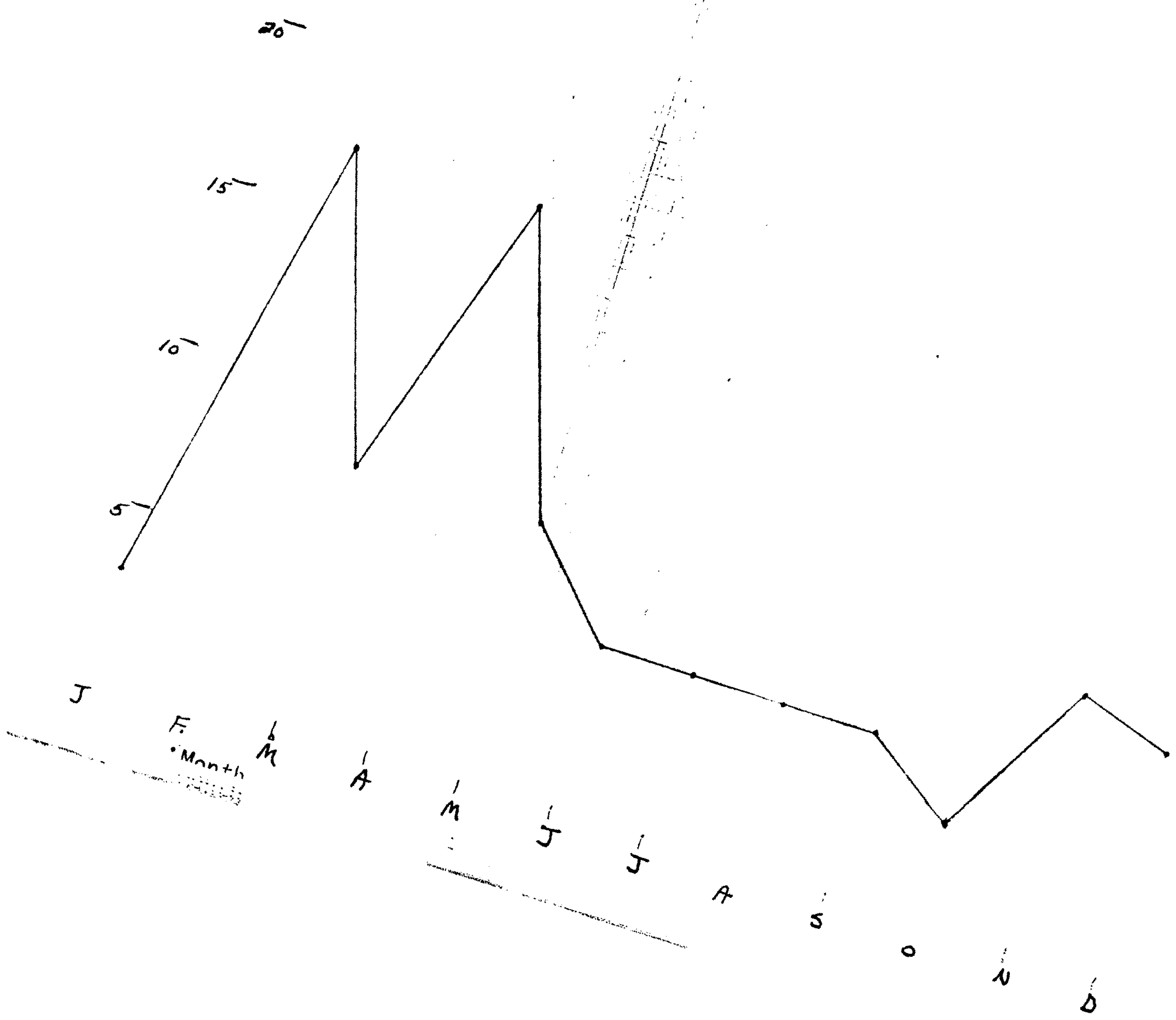


Combined respiratory deaths per 100000 -- 1970 Figure 2.22



Combined Respiratory Deaths per 100000 -- 1971

Figure 2.25



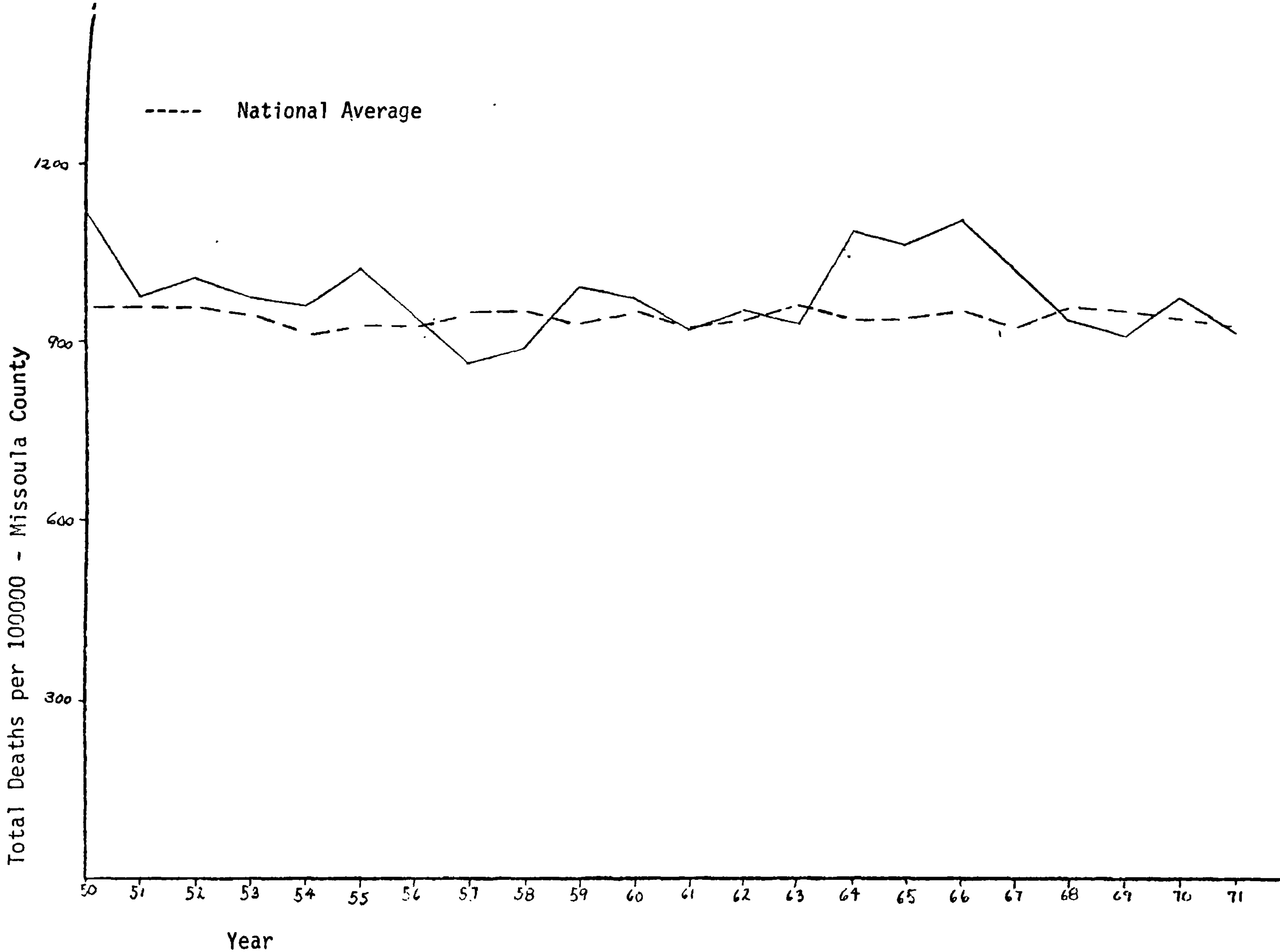


Figure 2.24

Total Deaths per 100000 population - Missoula County 1950 - 1971

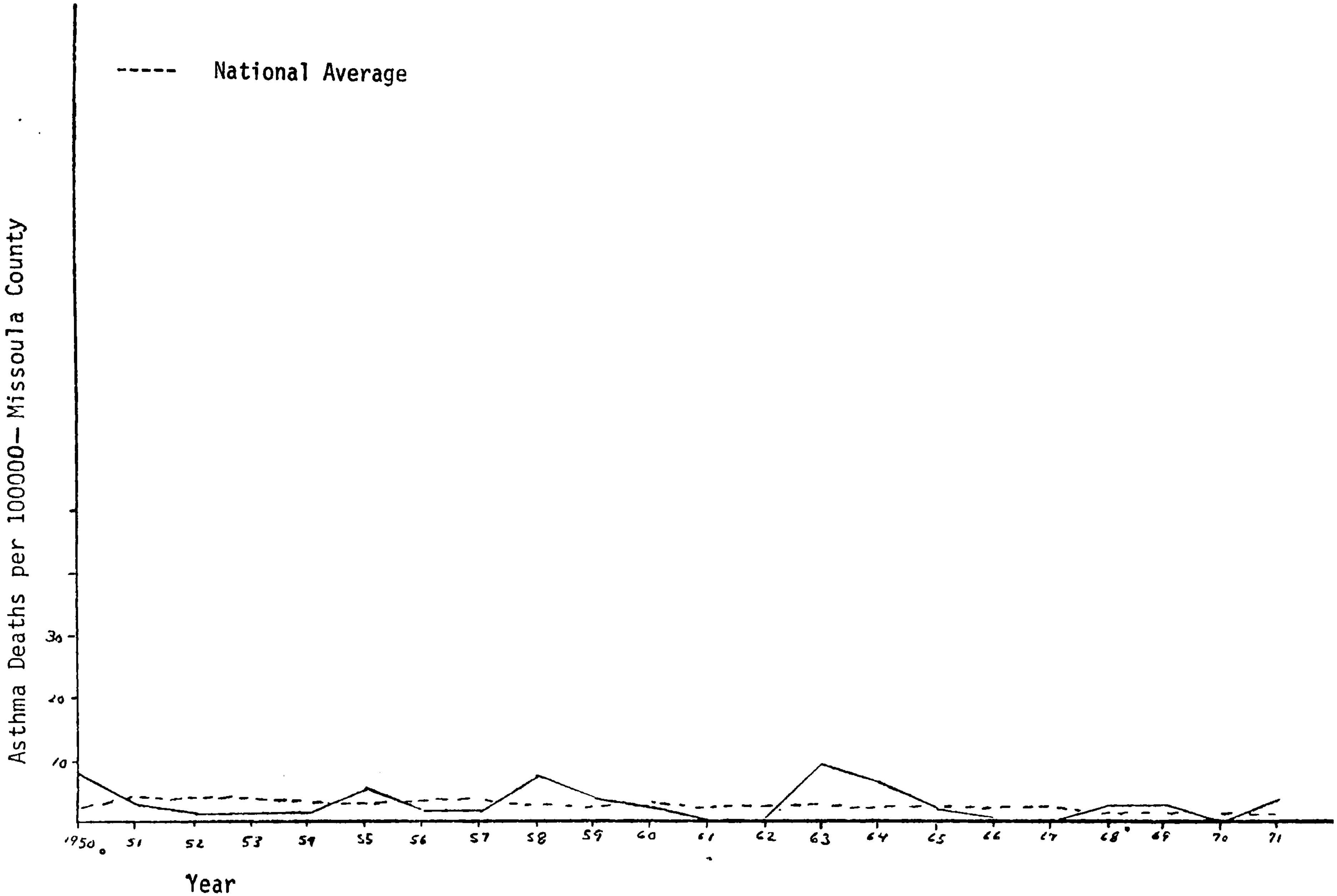


Figure 2.25

Asthma Deaths per 100000 Population - Missoula County 1950 - 1971

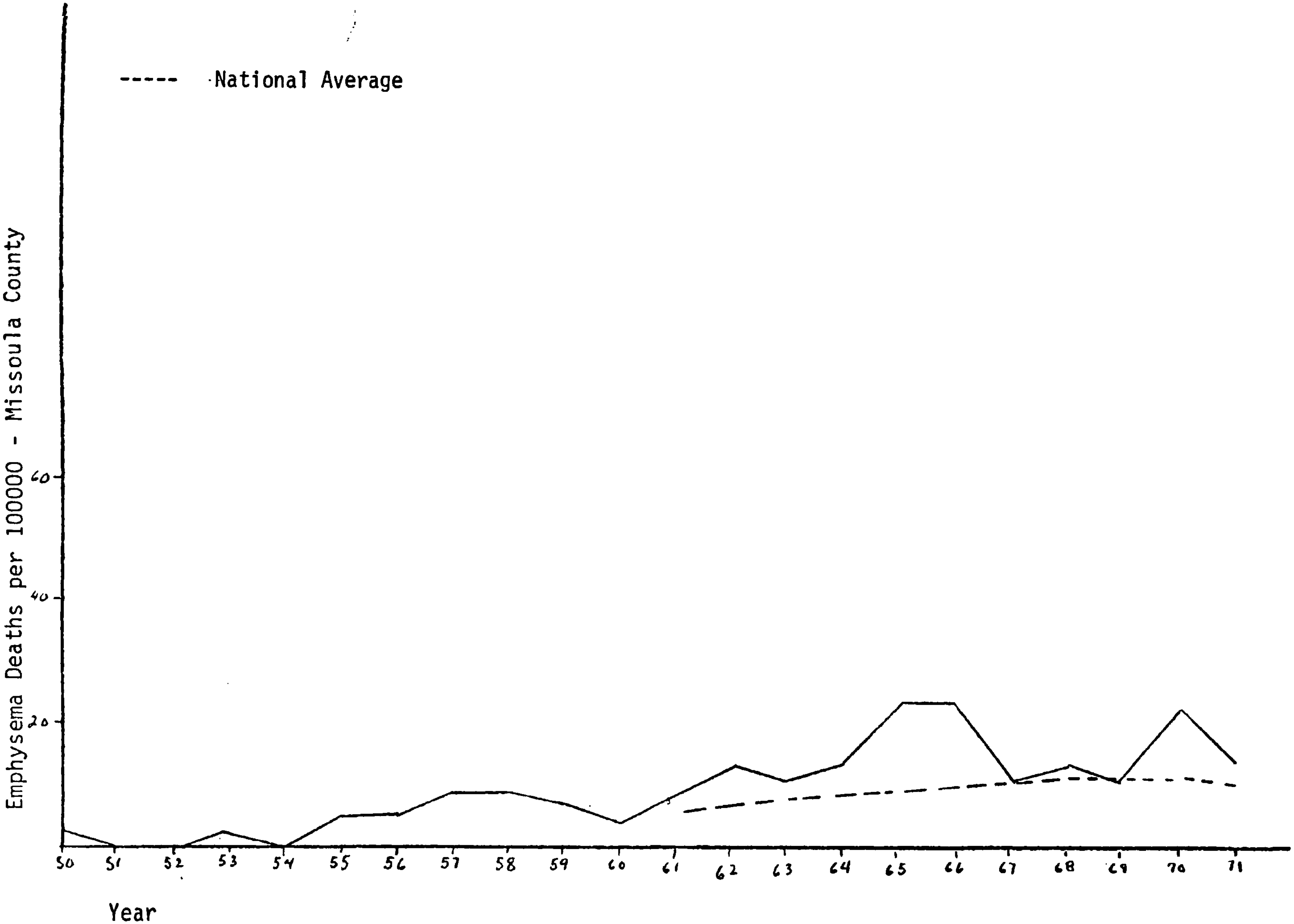


Figure 2.26

Emphysema Deaths per 100000 population - Missoula County 1950 - 1971

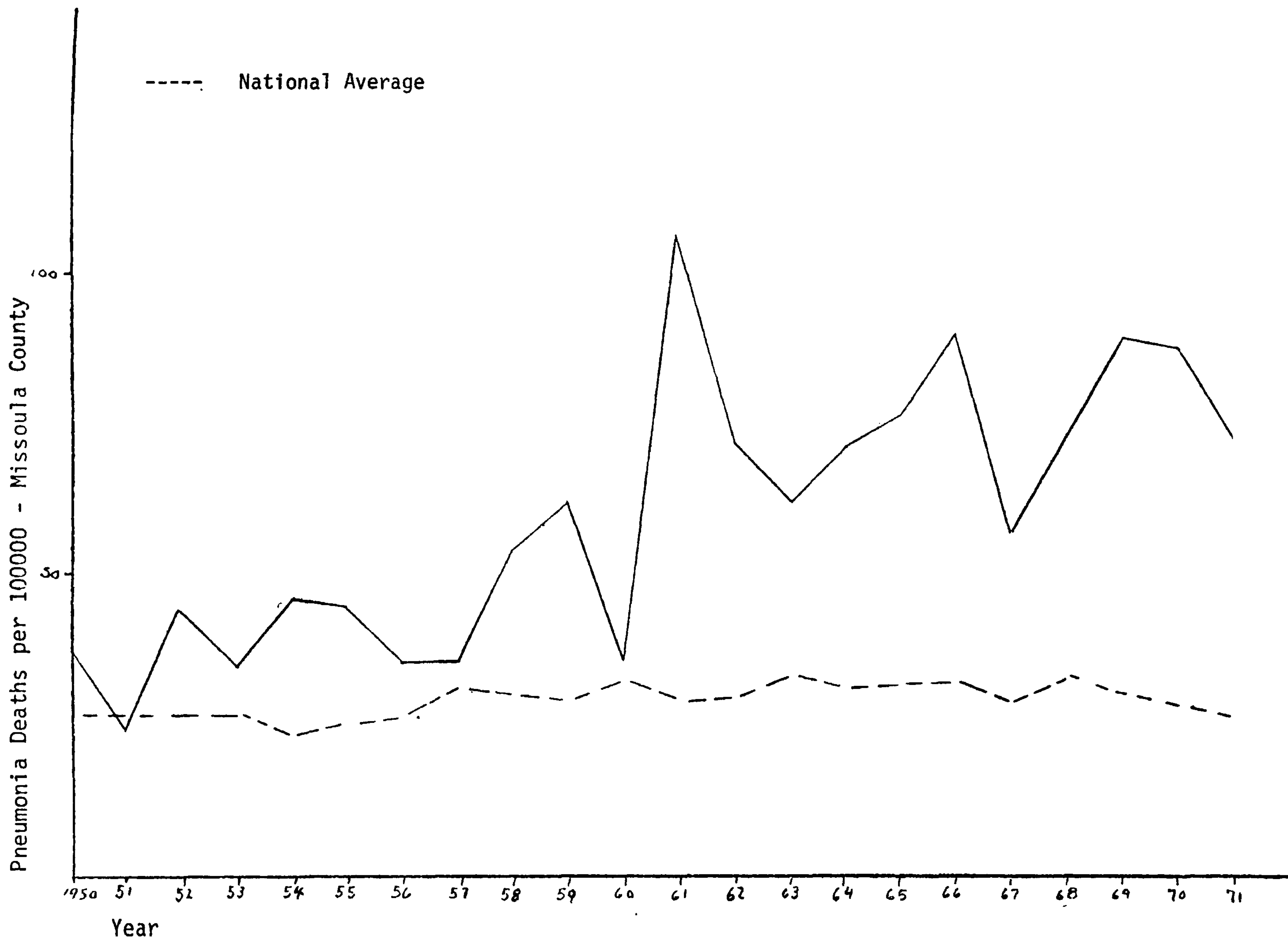
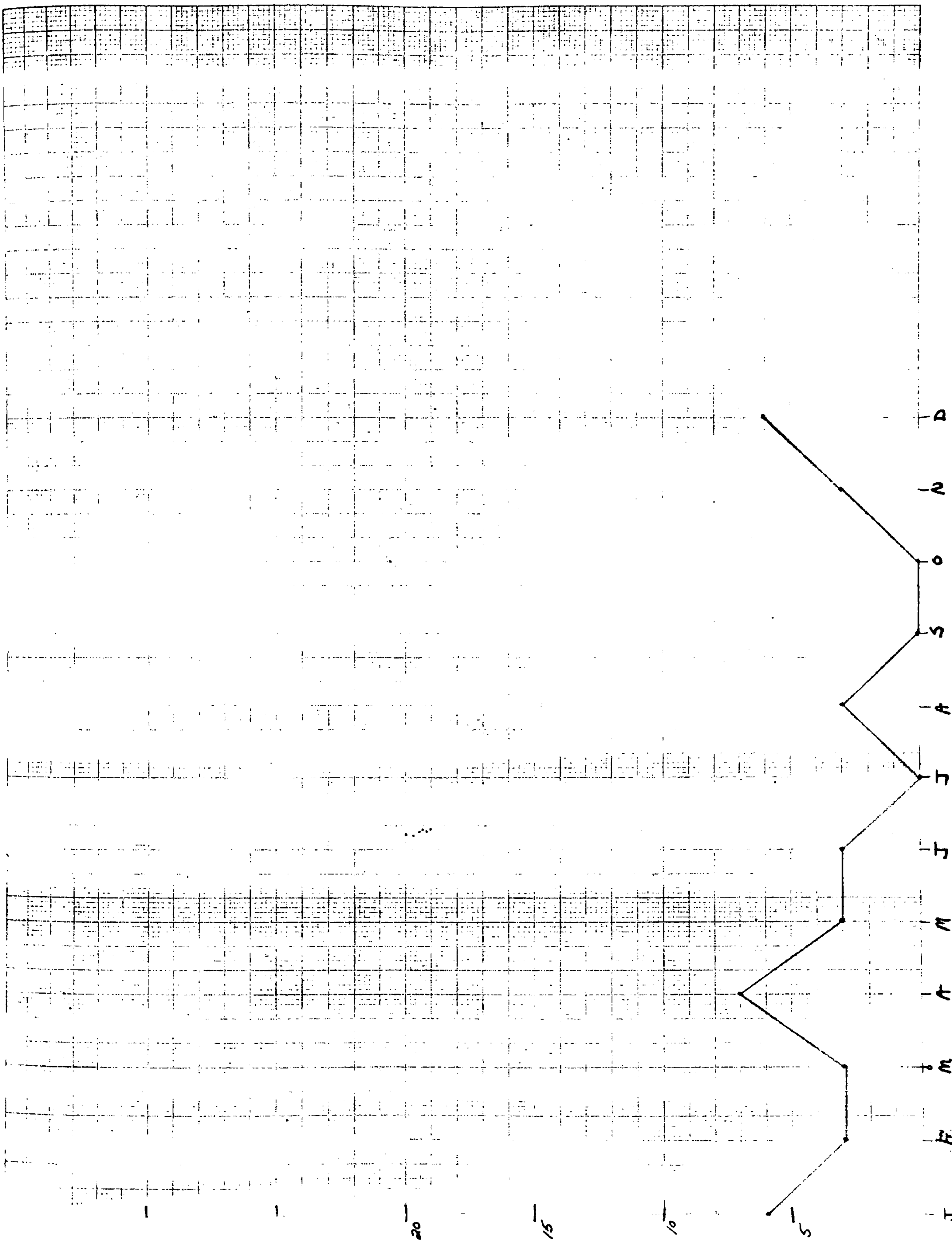


Figure 2.27

Pneumonia Deaths per 100000 population - Missoula County 1950 - 1971



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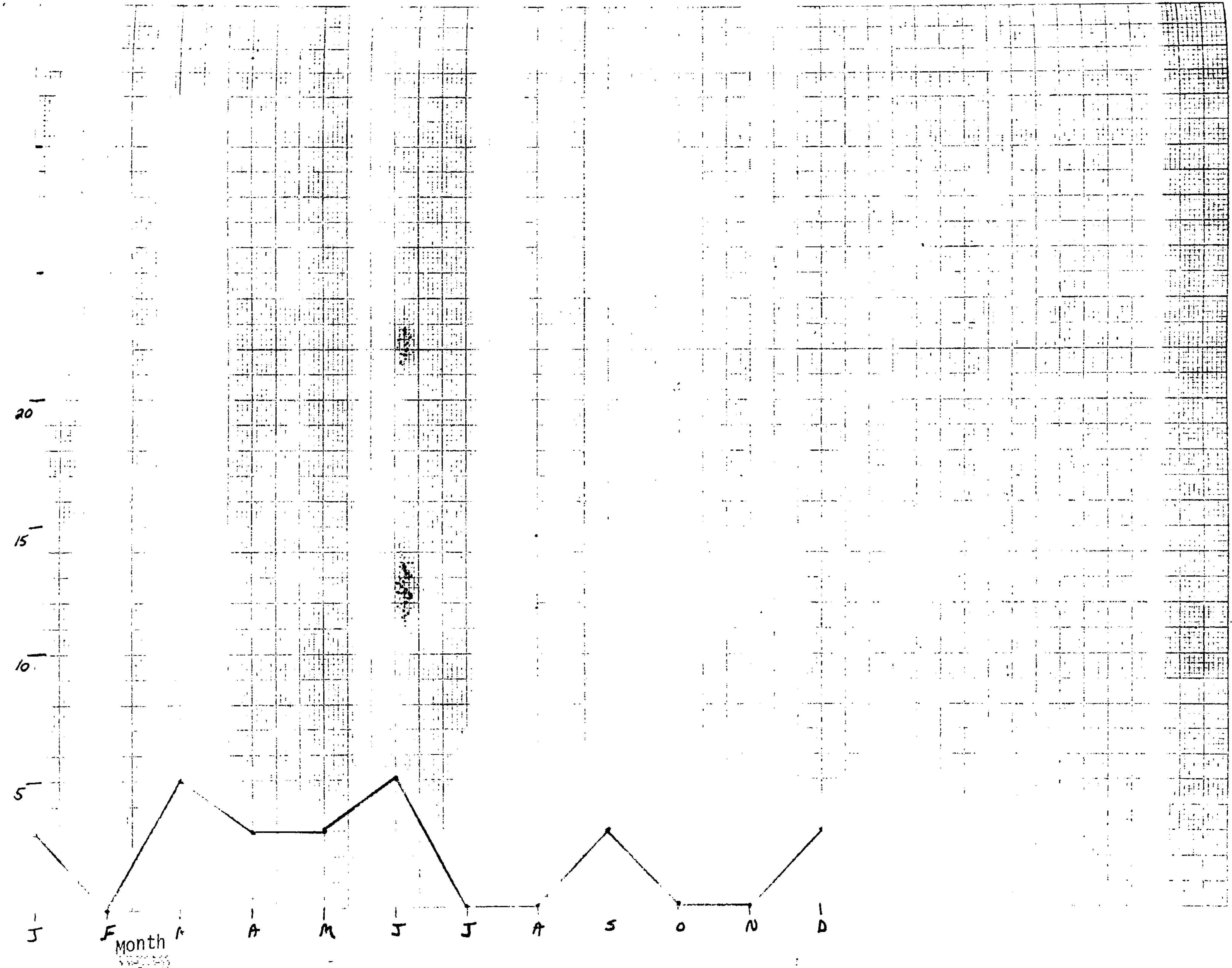
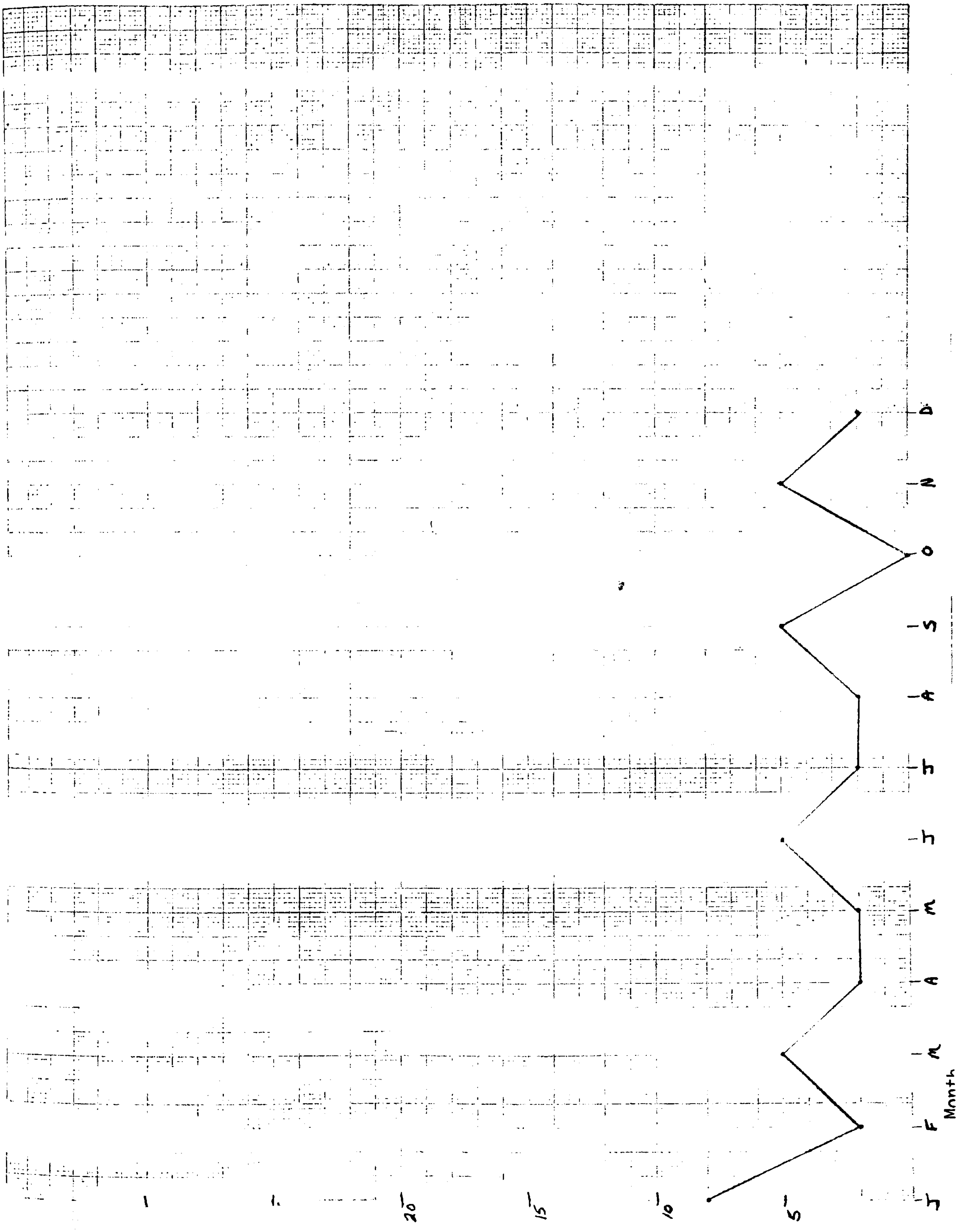
Pneumonia Deaths per 100000 1981 Figure 2.29



p.77 not missing - pages misnumbered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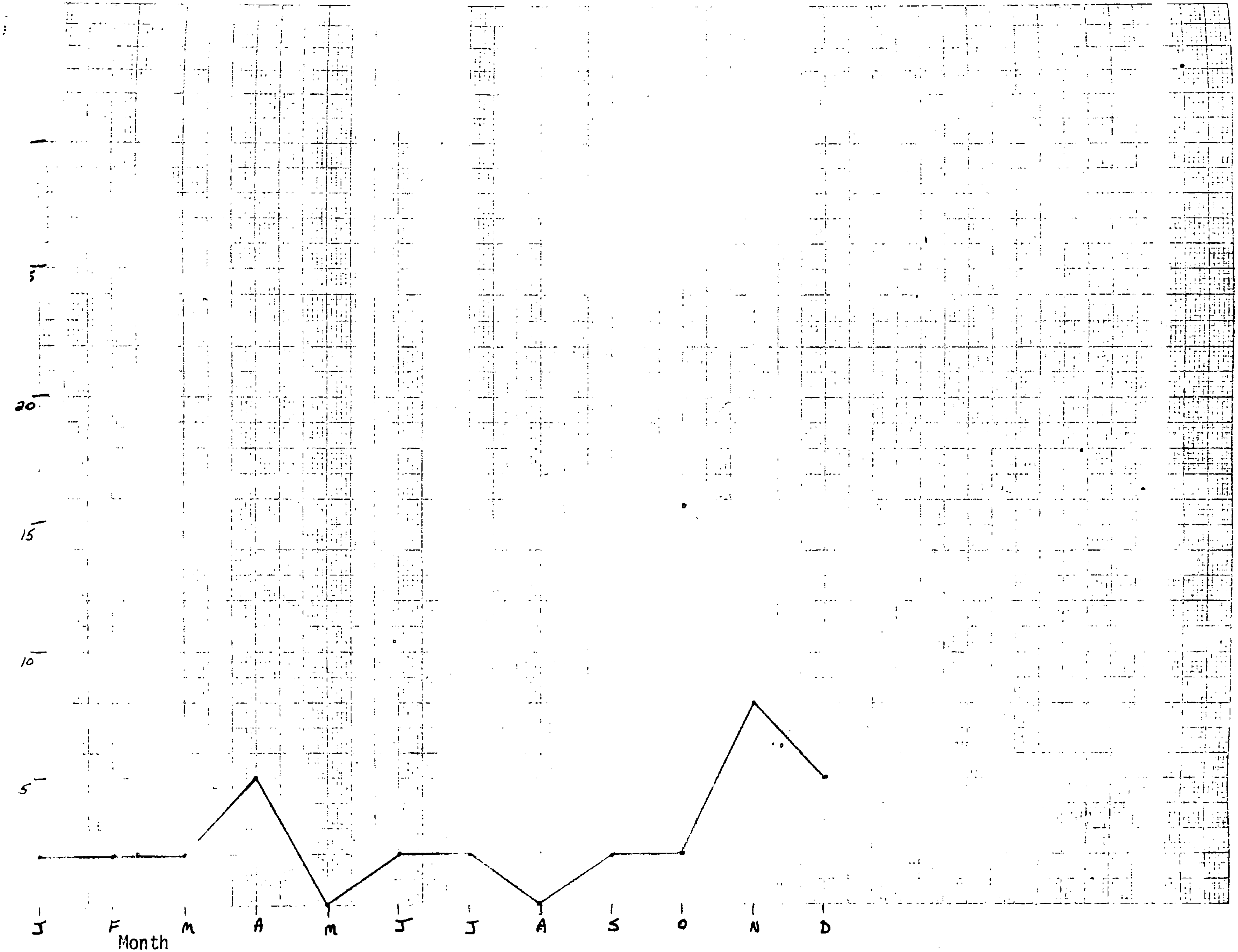
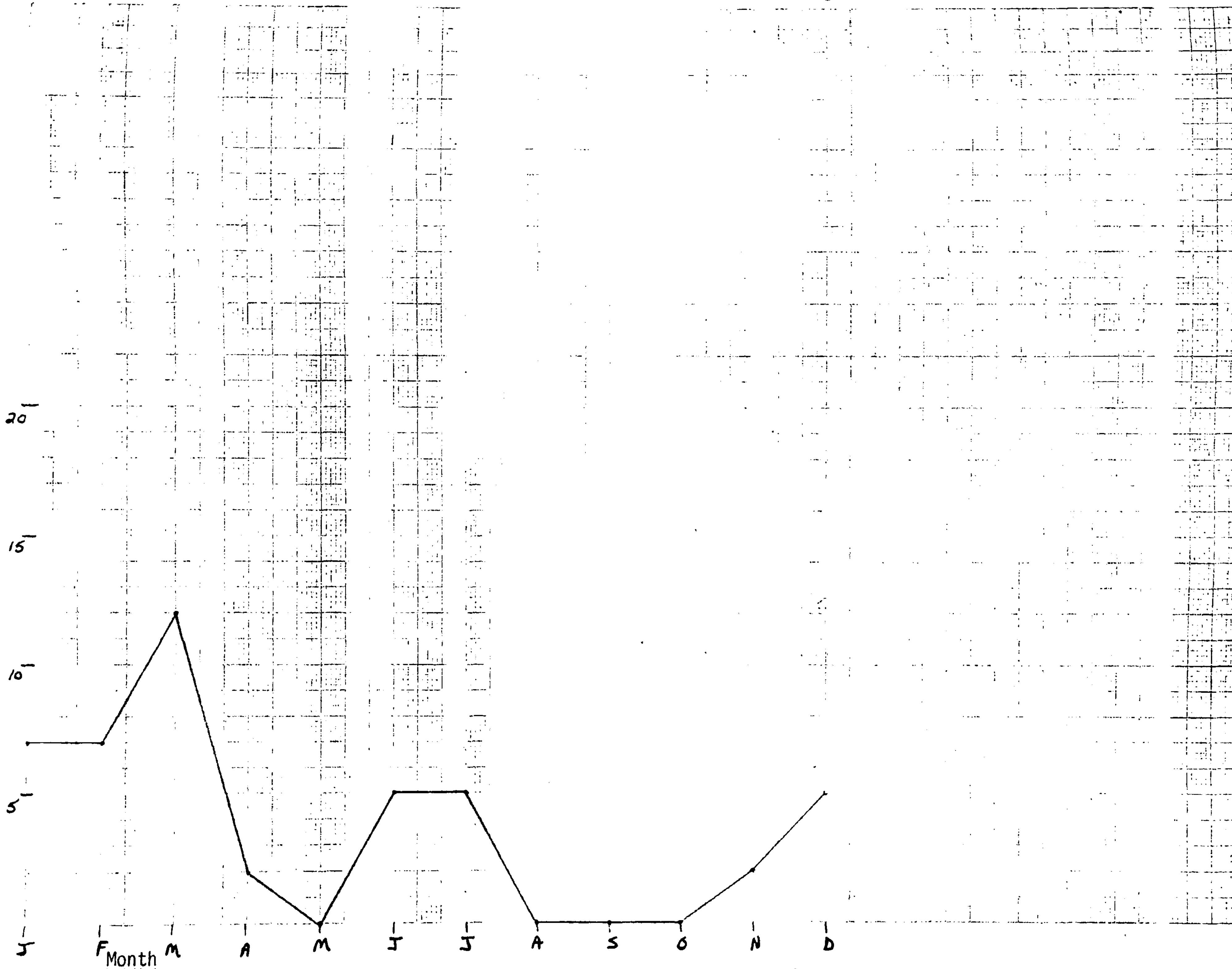
Pneumonia Deaths per 100000 -- 195[illegible] Figure 2.31

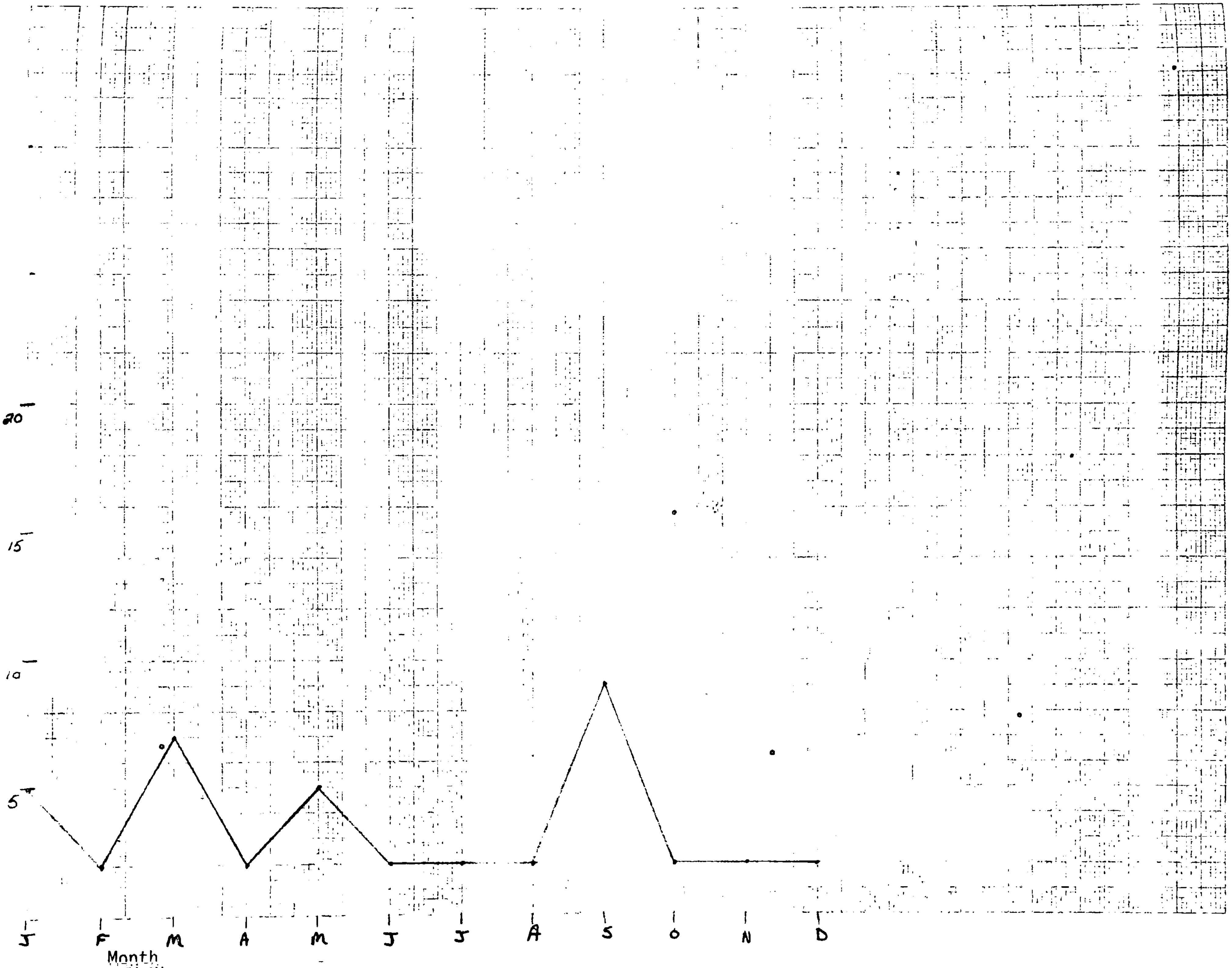


Pneumonia Deaths per 100000 -- 1954

Figure 2.32



-83-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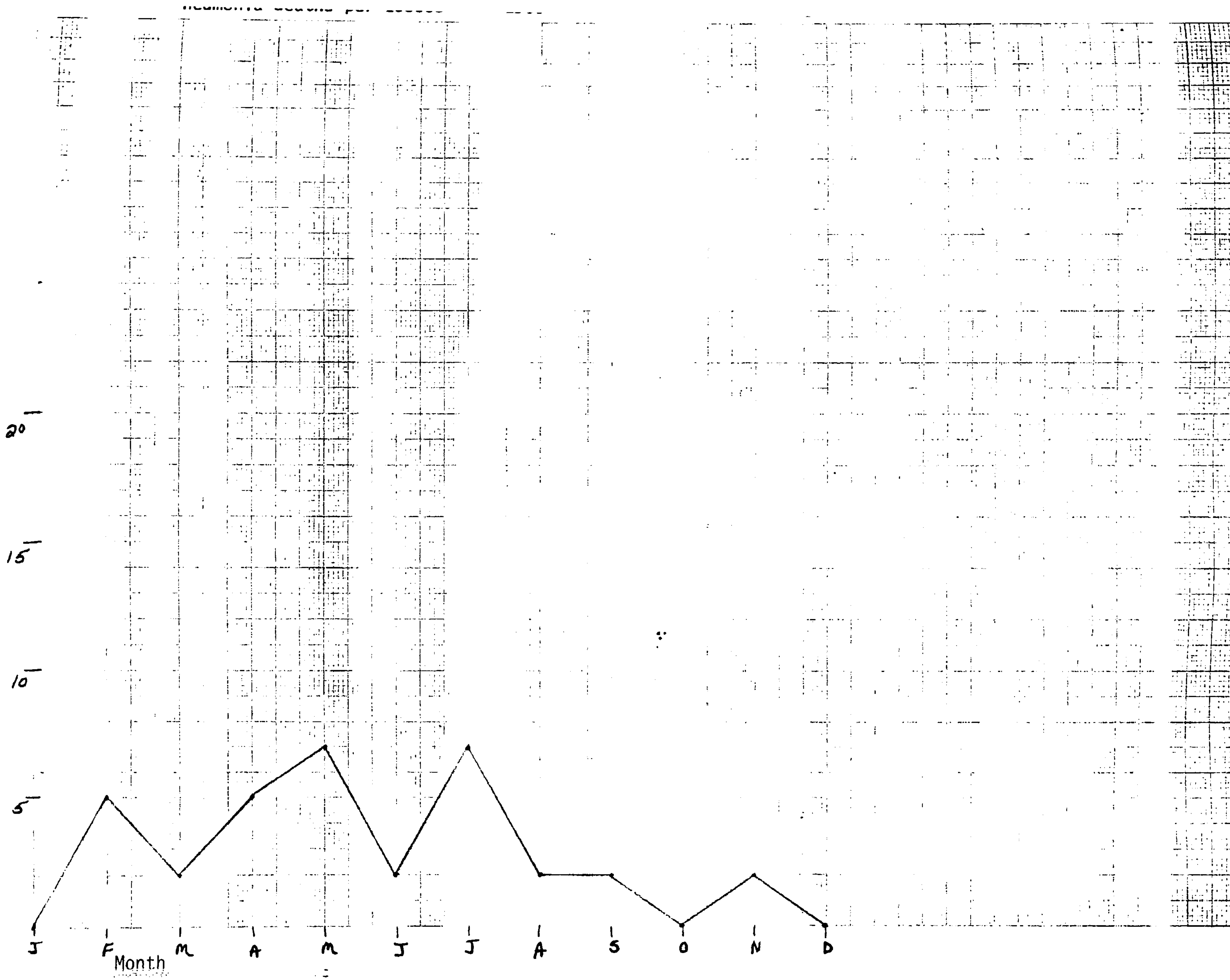
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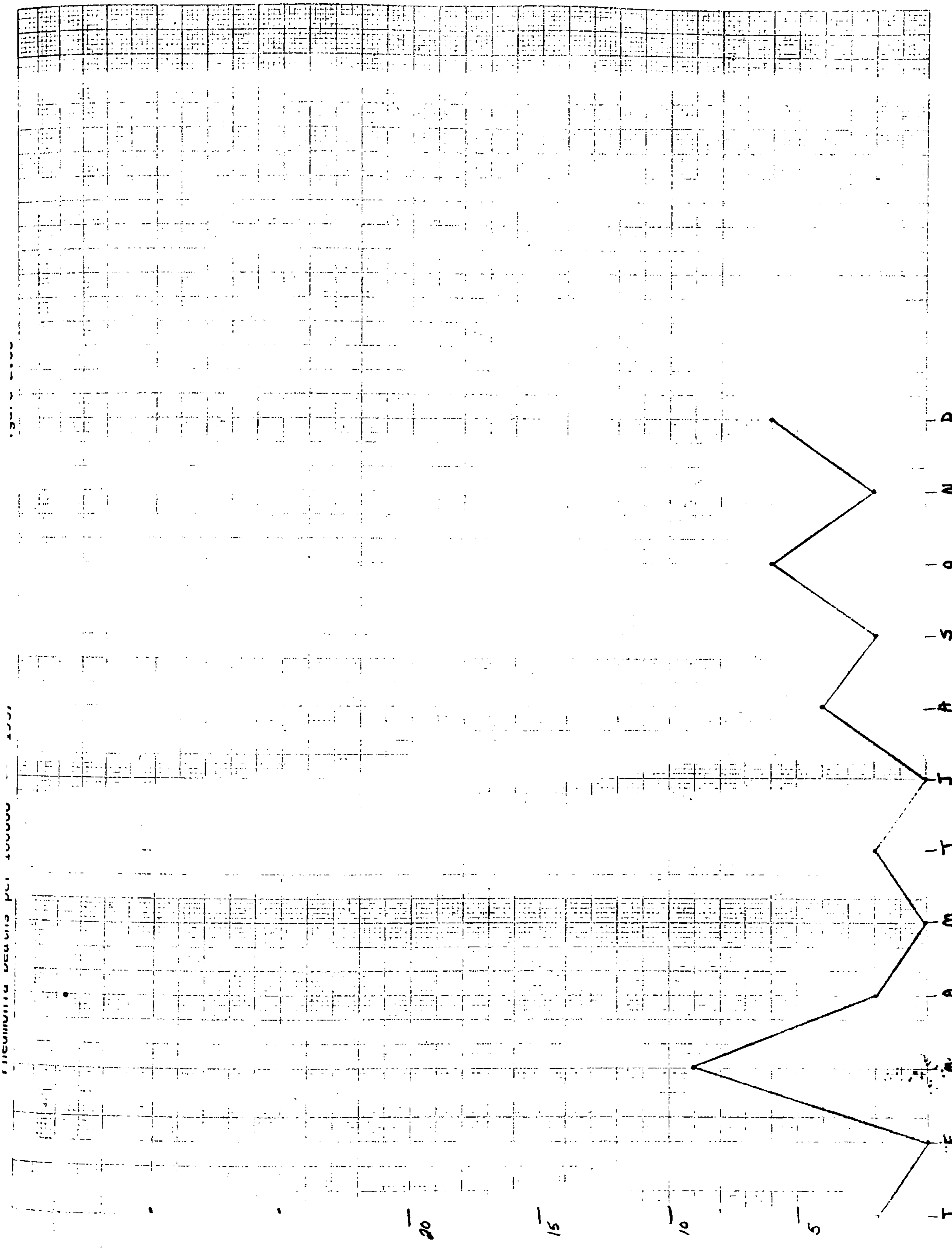
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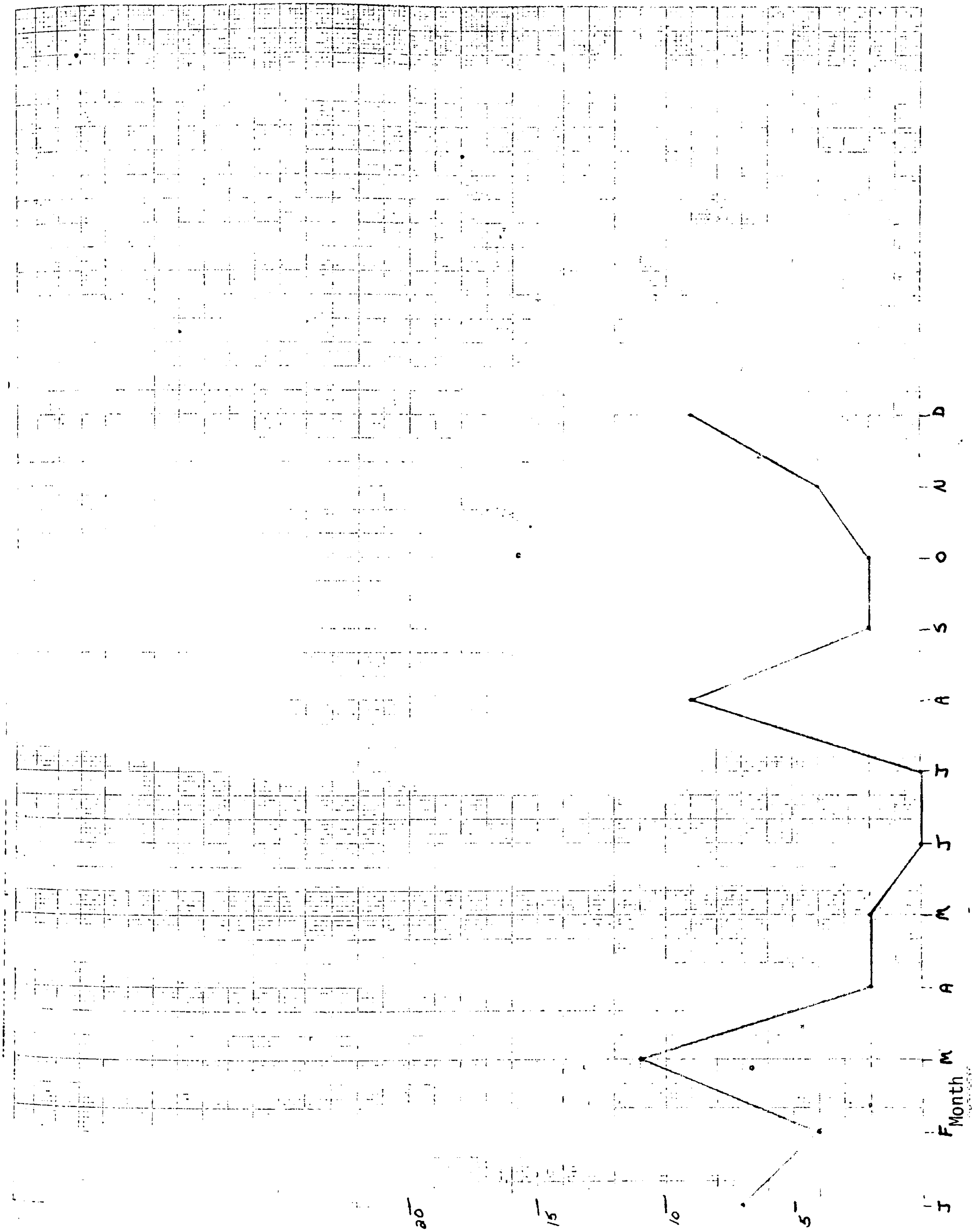
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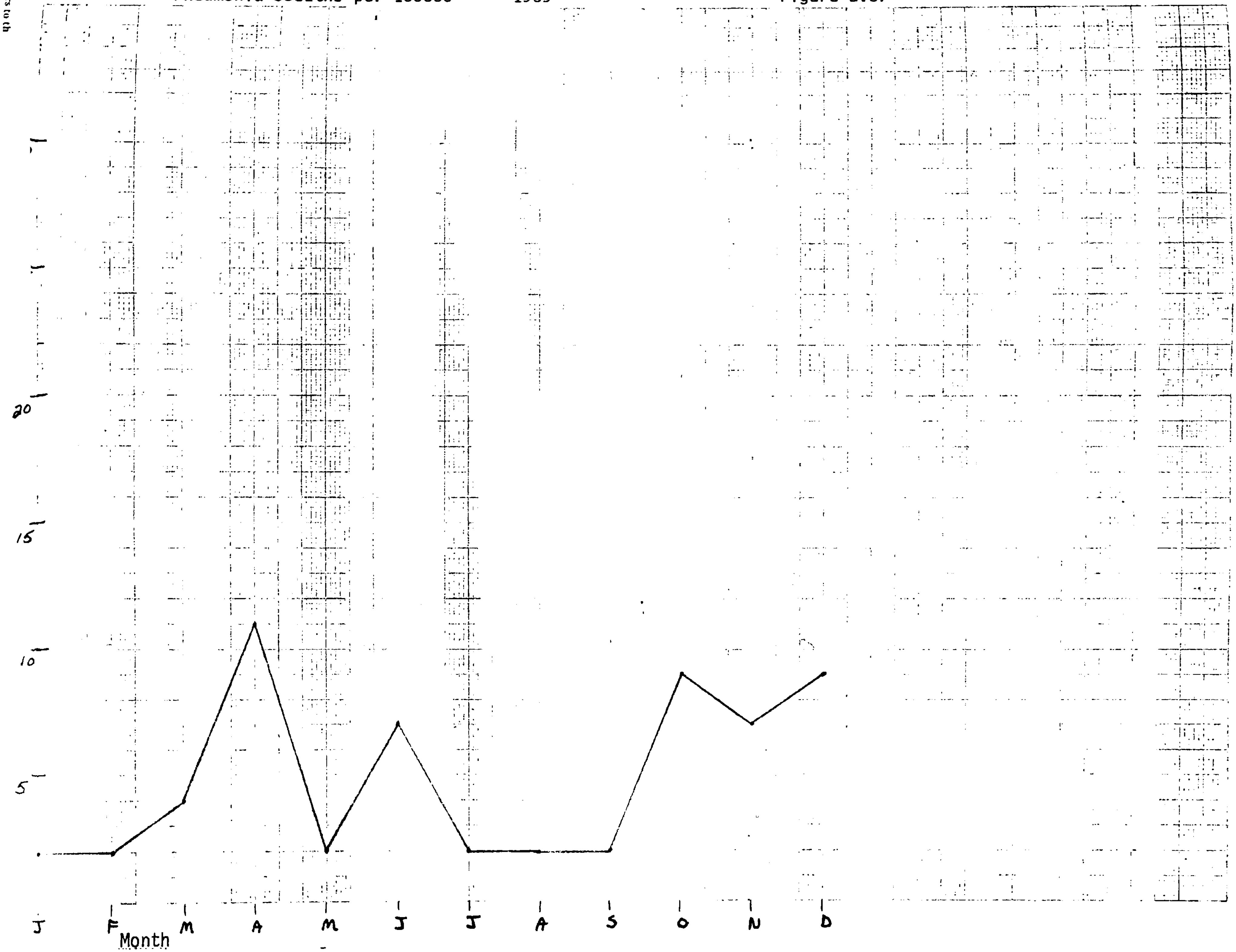
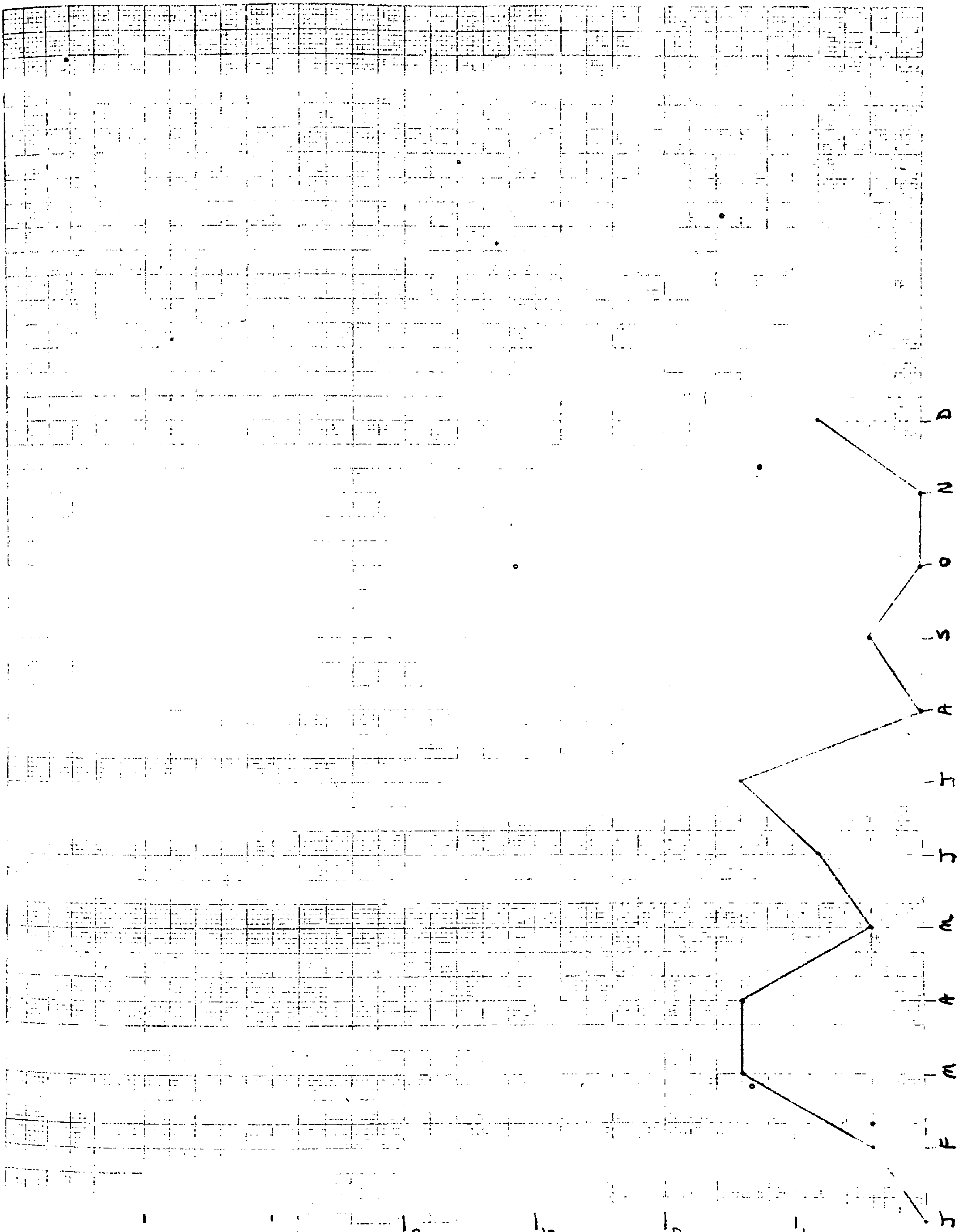
Pneumonia SDeaths per 100000 -- 1959

Figure 2.37





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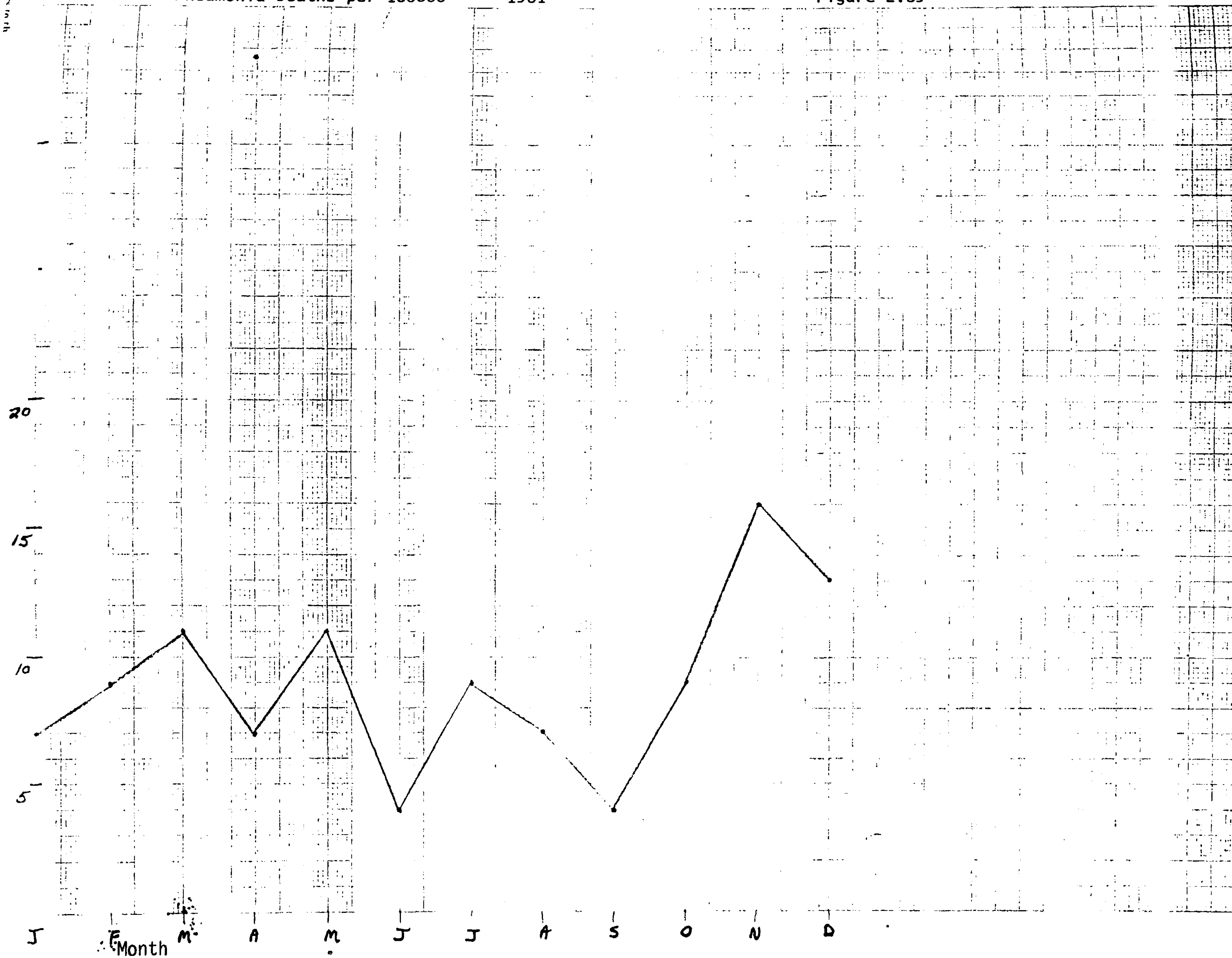
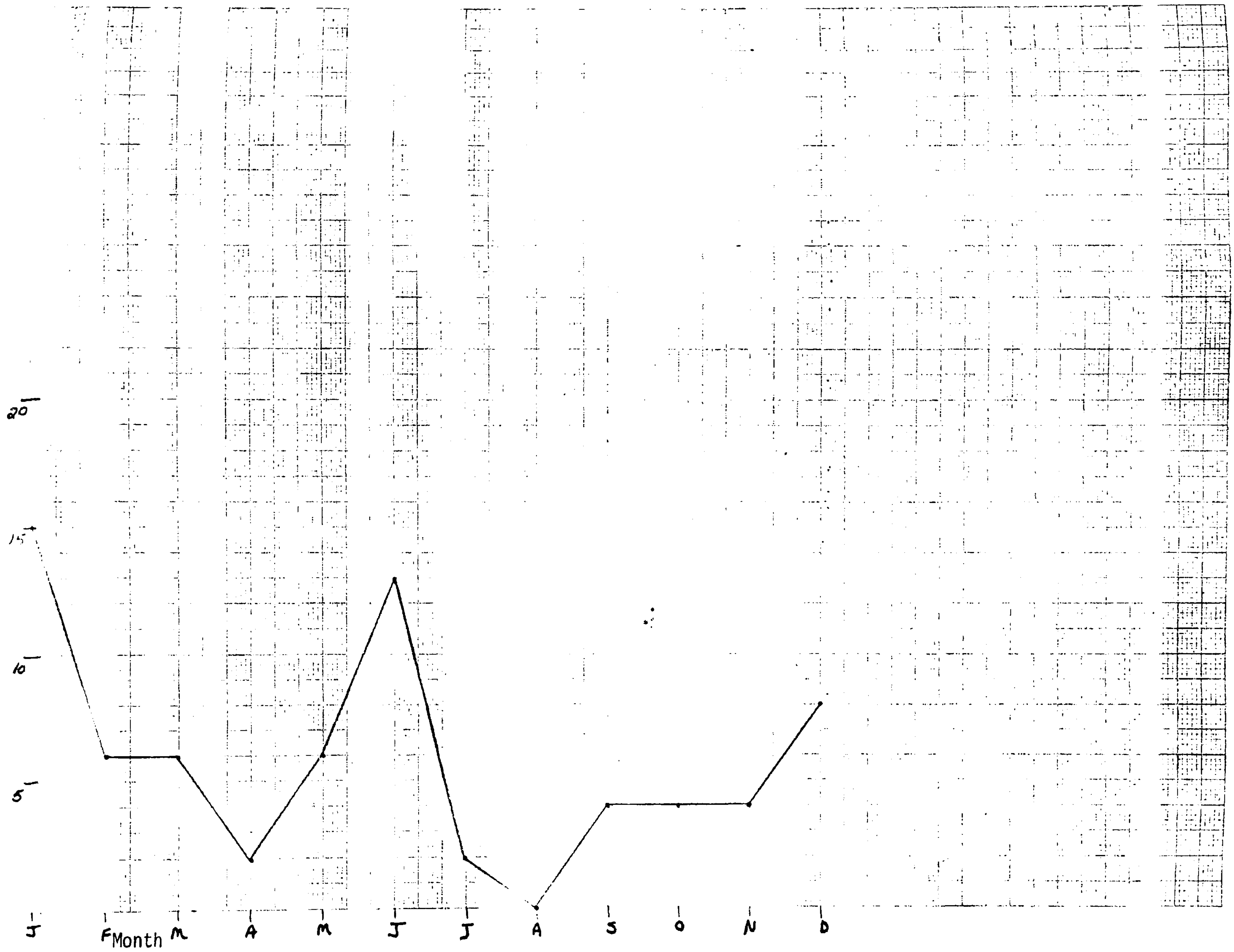
Pneumonia Deaths per 100000 -- 1961

Figure 2.39

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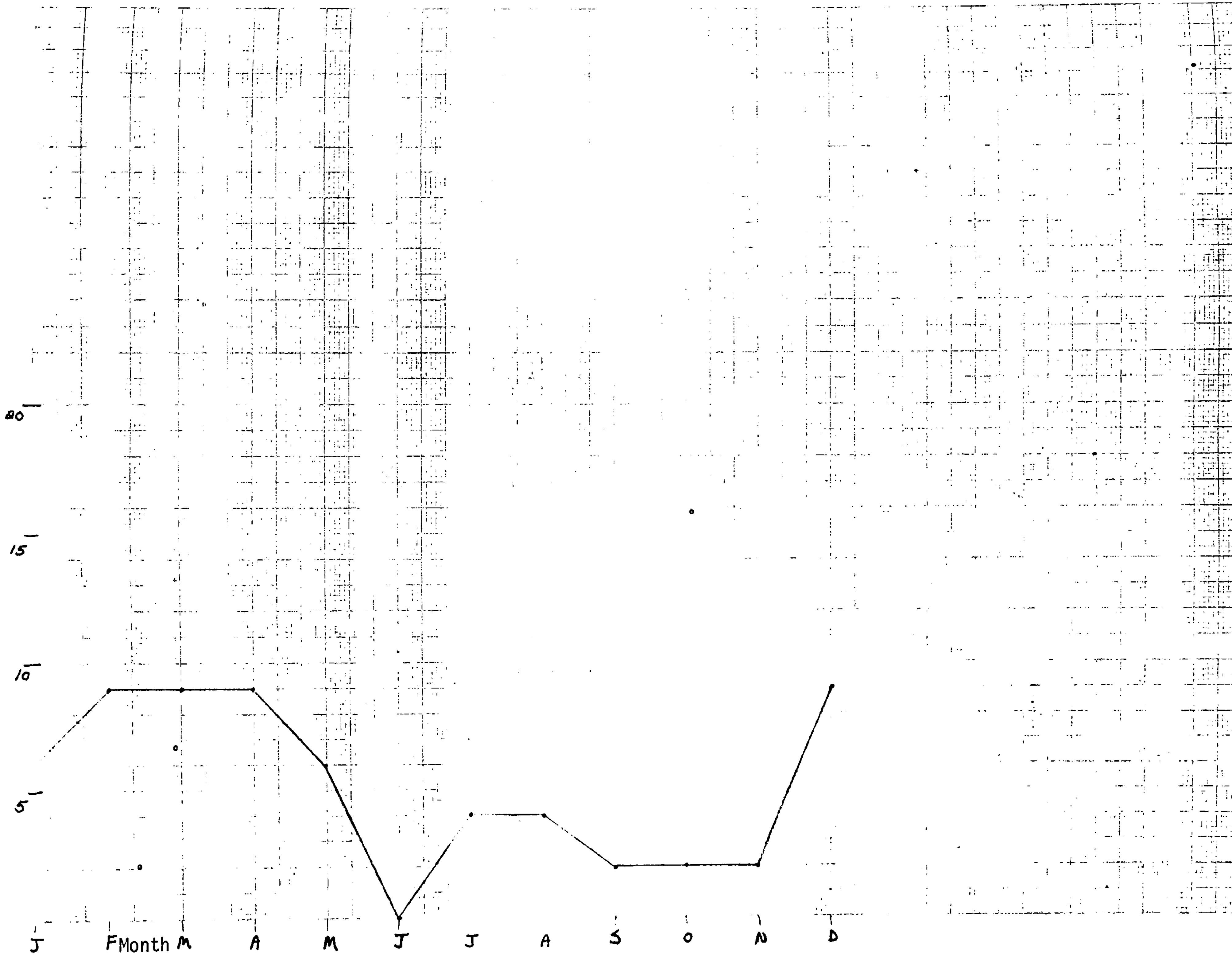
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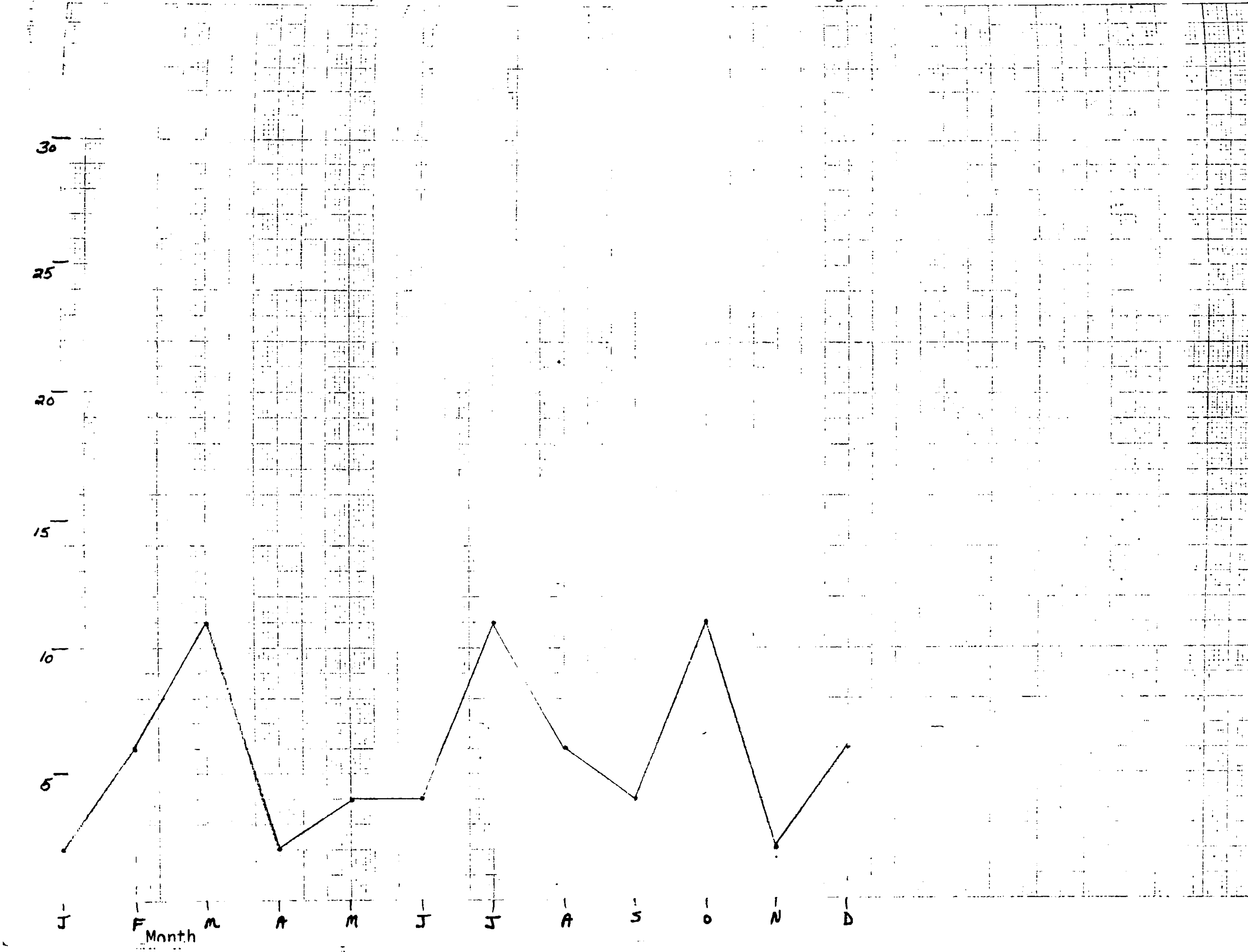
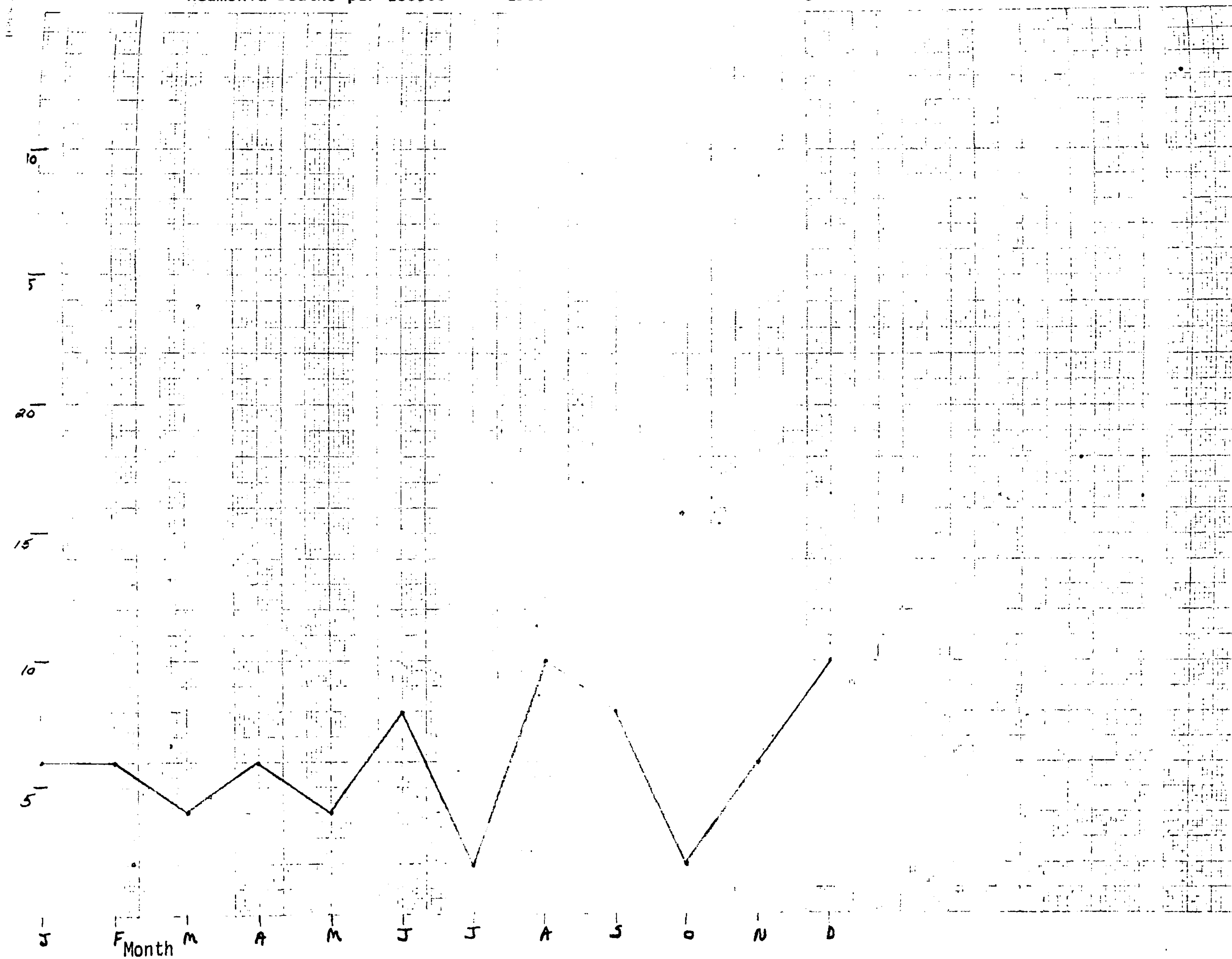
Pneumonia Deaths per 100000 -- 1964 Figure 2.42



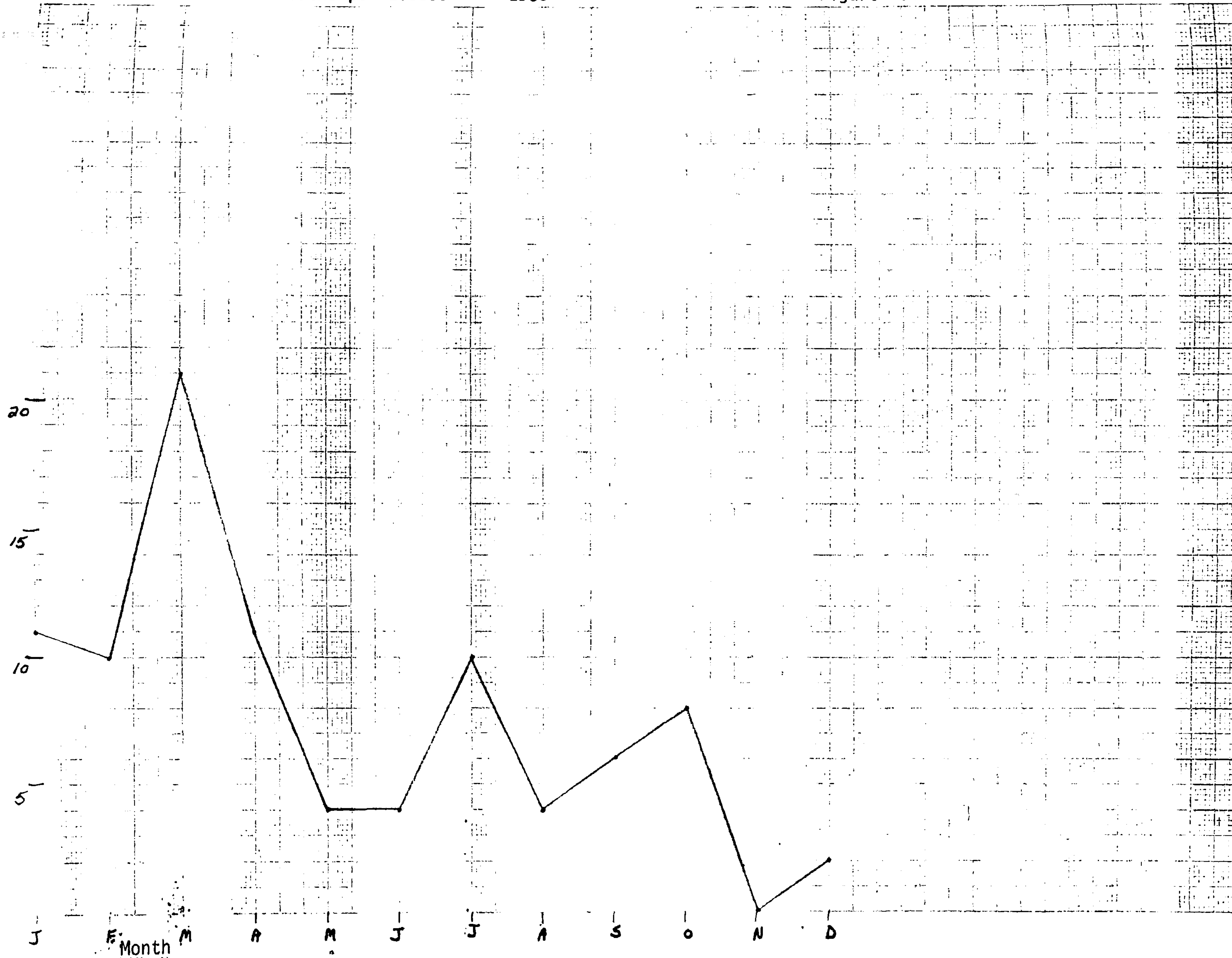
Pneumonia Deaths per 100000 -- 1985

Figure 2.43



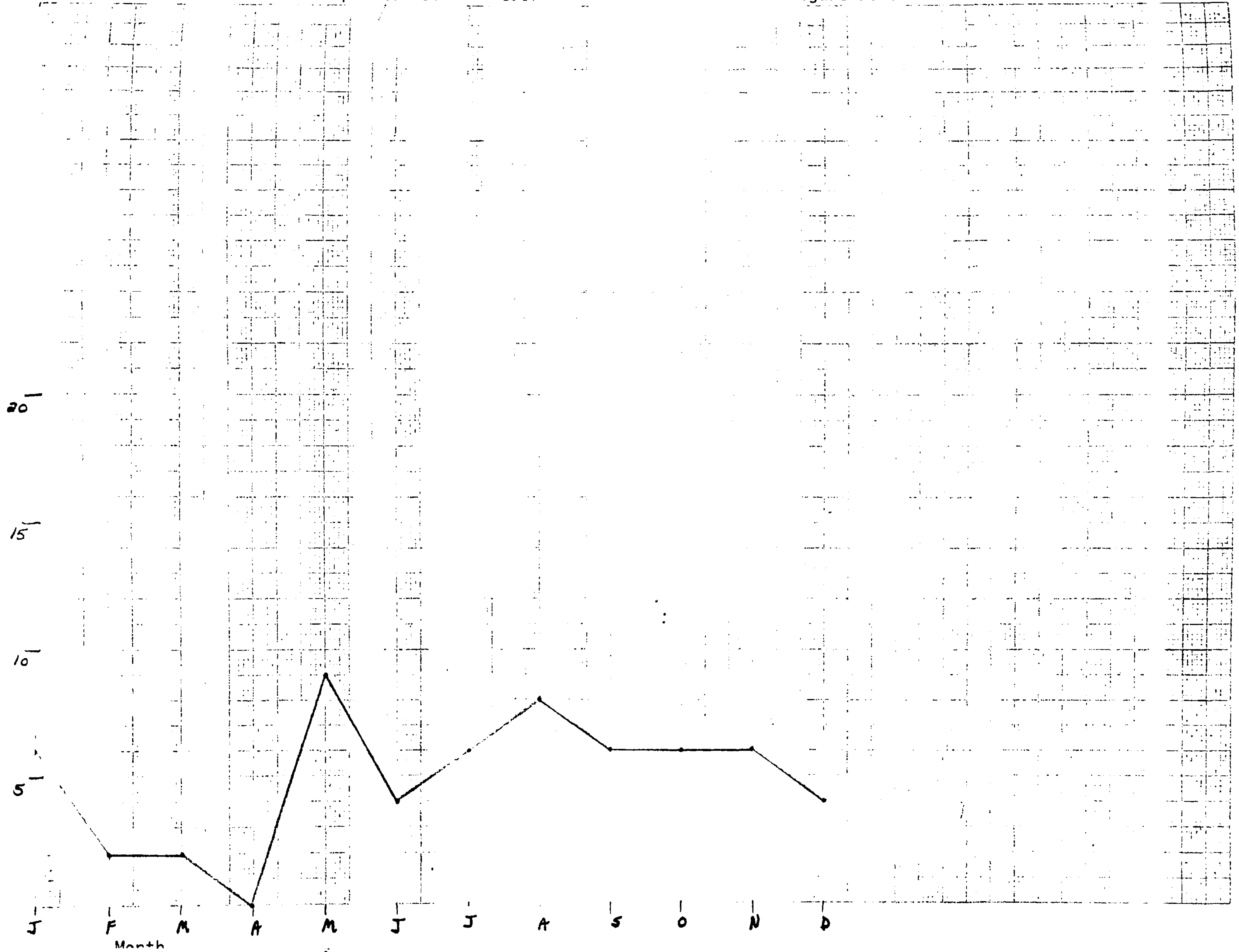
Pneumonia Deaths per 100000 -- 1966

Figure 2.44

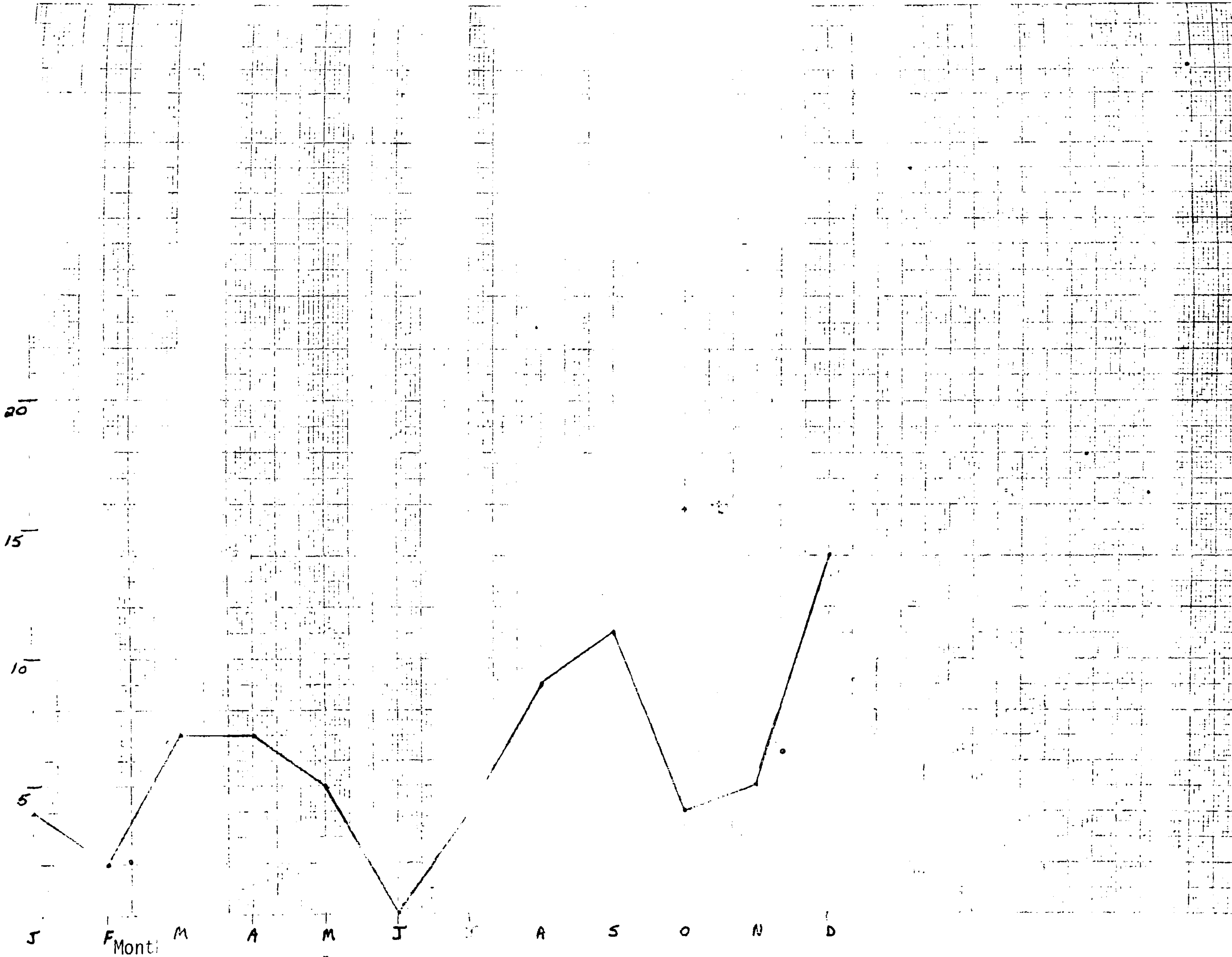


Pneumonia Deaths per 100000 -- 1967

Figure 2.45

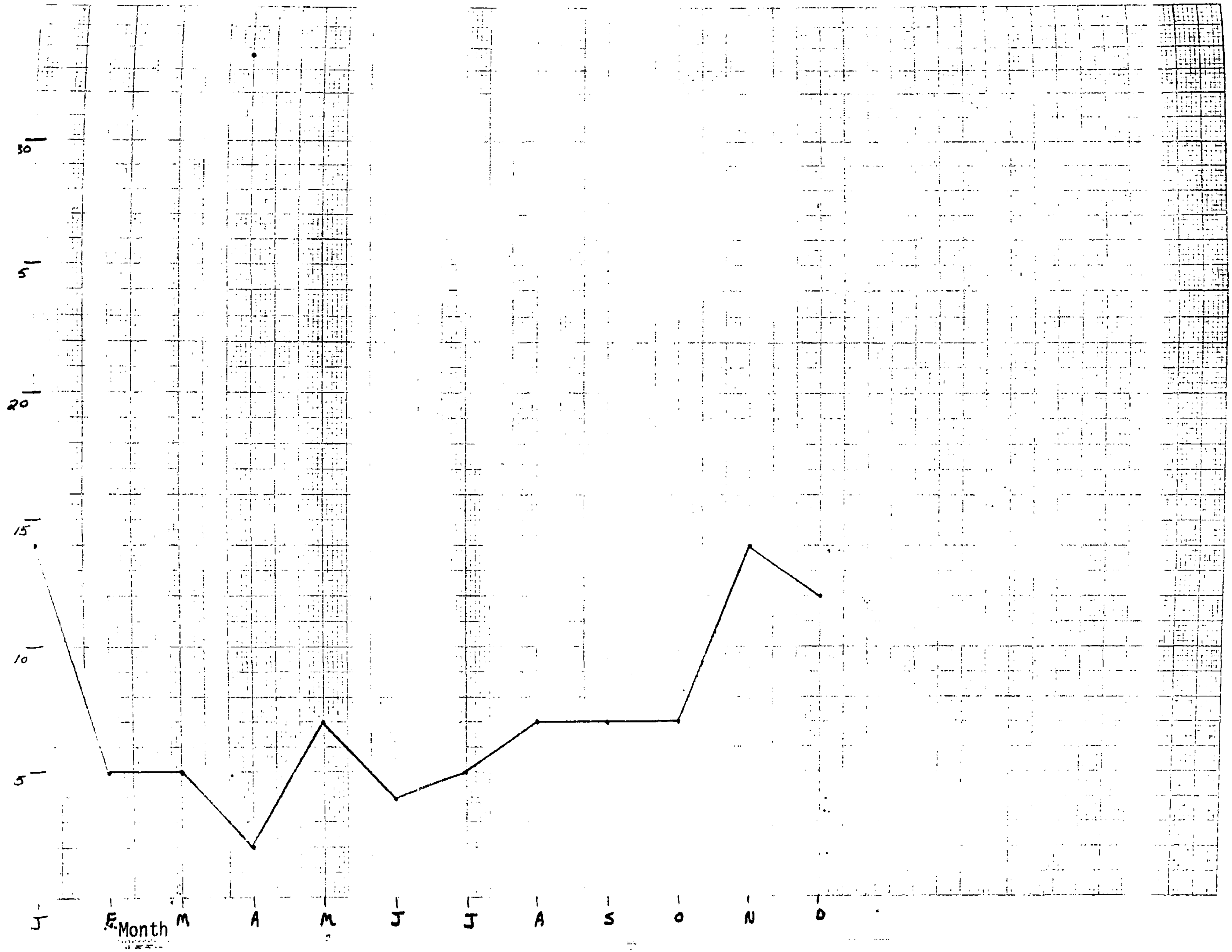


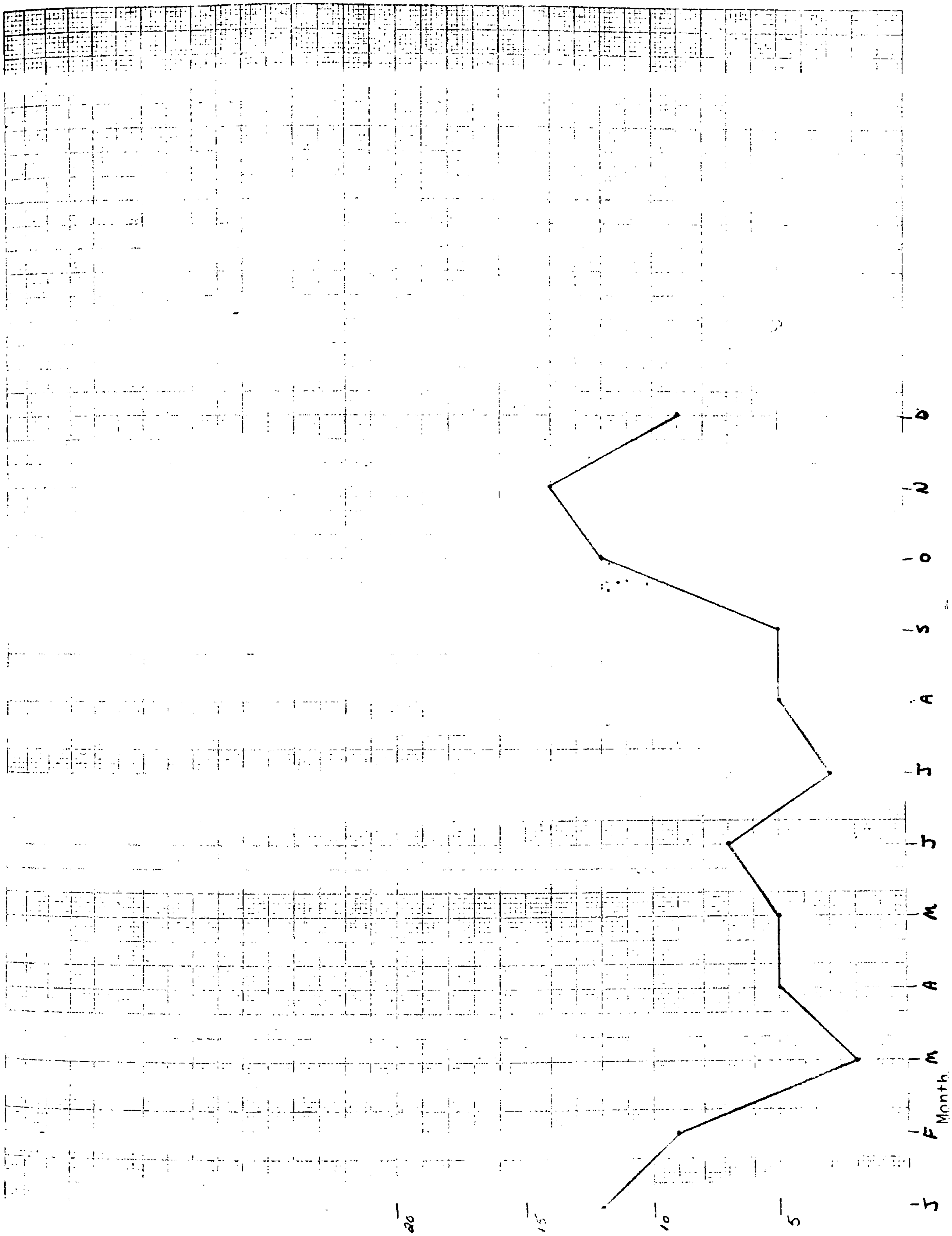
Pneumonia Deaths per 100000 -- 1968 Figure 2.46



Pneumonia Deaths per 100000 -- 1969

Figure 2.47

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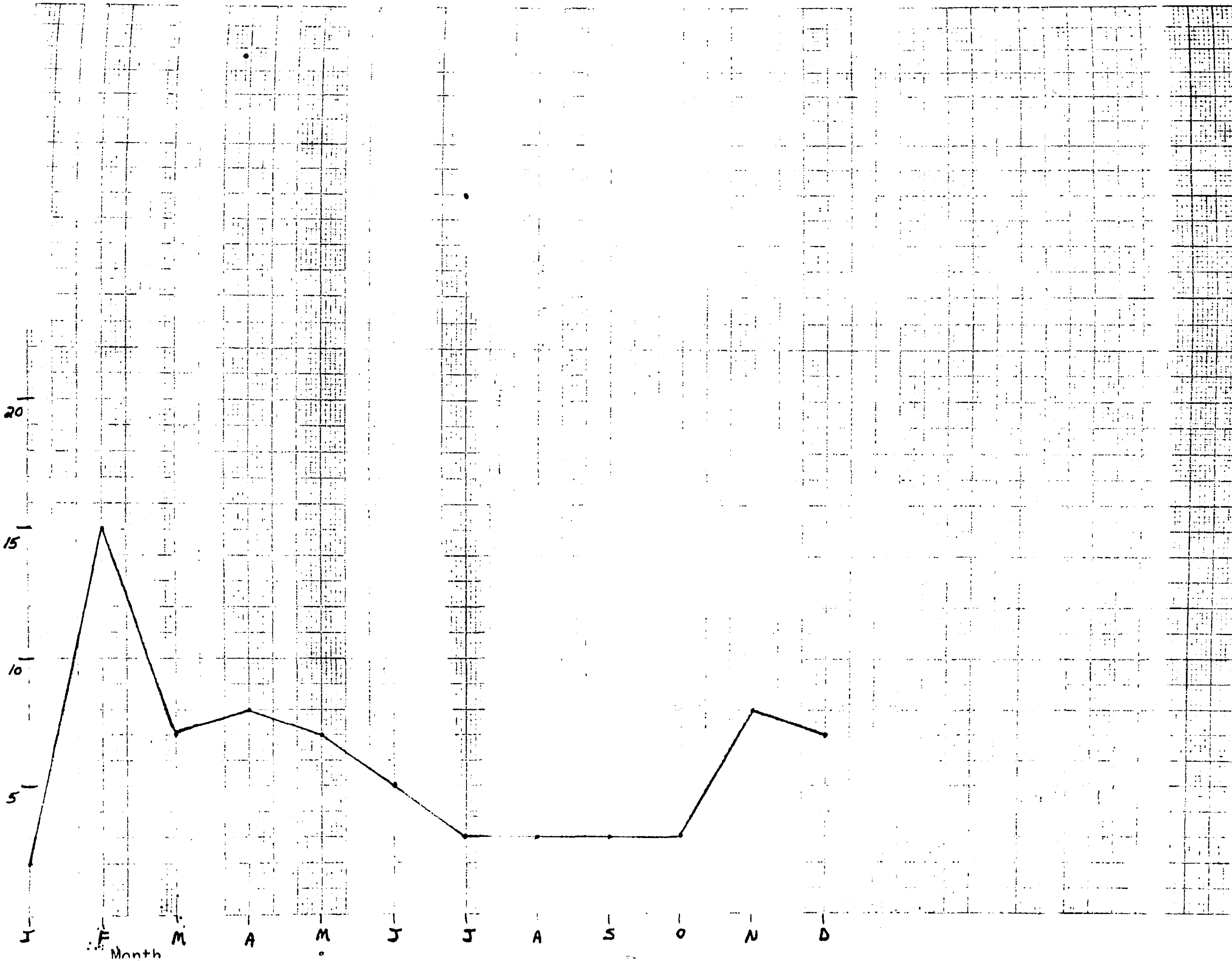
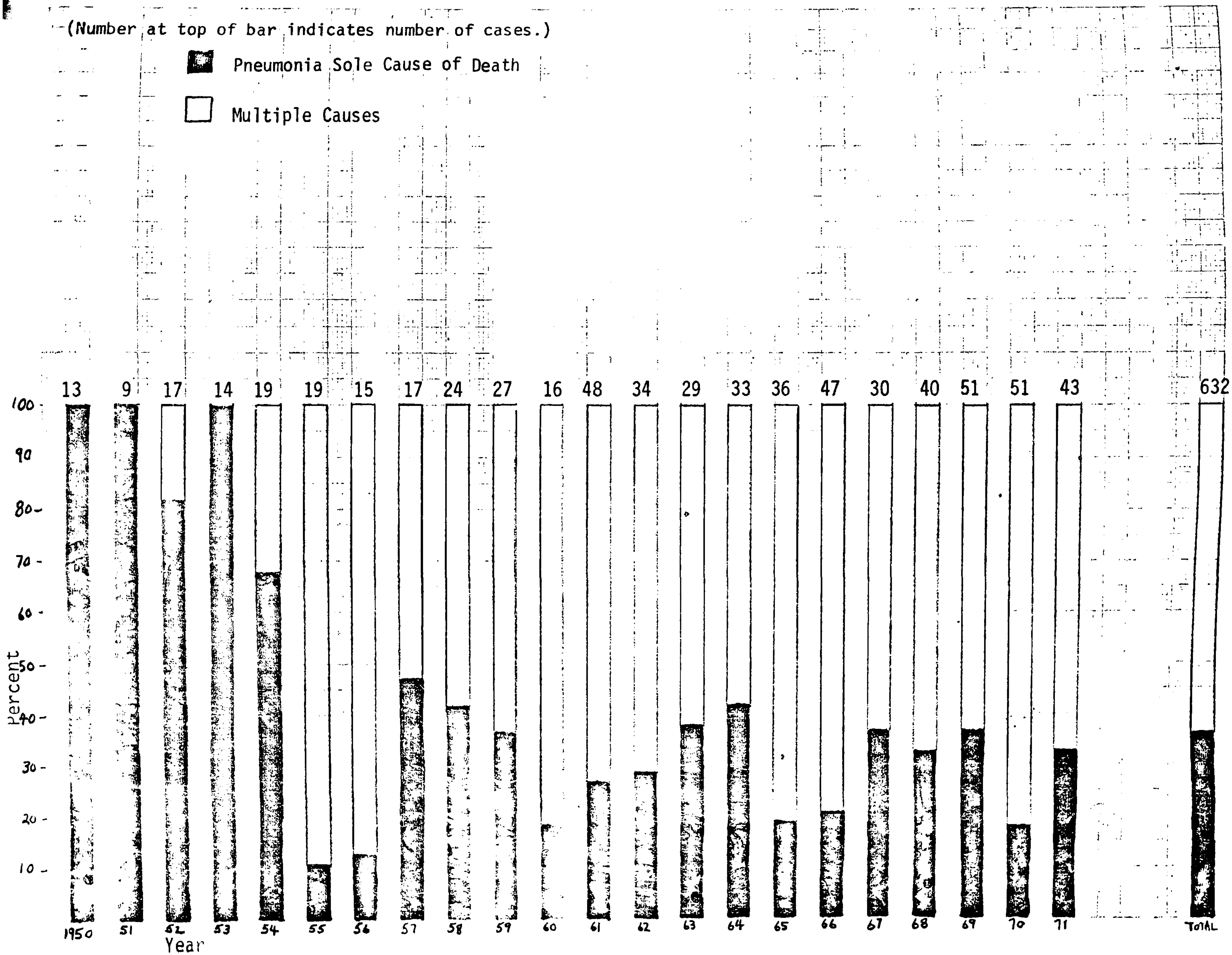
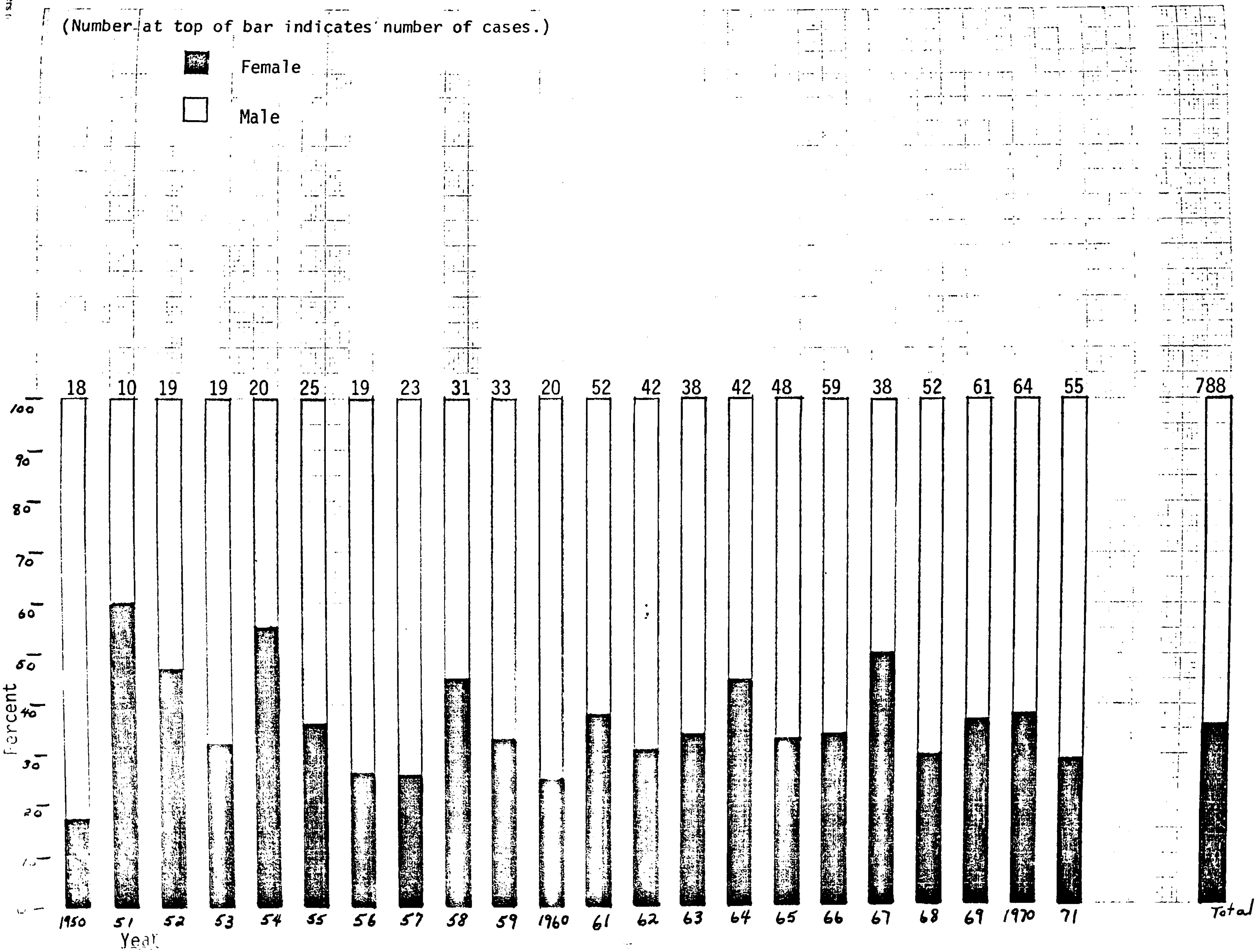
Pneumonia Deaths per 100000 -- 1971

Figure 2.49




(Number at top of bar indicates number of cases.)
Pneumonia Sole Cause of Death
Multiple Causes
13 9 17 14 19 19 15 17 24 27 16 48 34 29 33 36 47 30 40 51 51 43 632
100
90
80
70
60
50
40
30
20
10
Percent
1950 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 TOTAL
Year

Sexual Differentiation - Combined Respiratory Deaths Figure 2.51



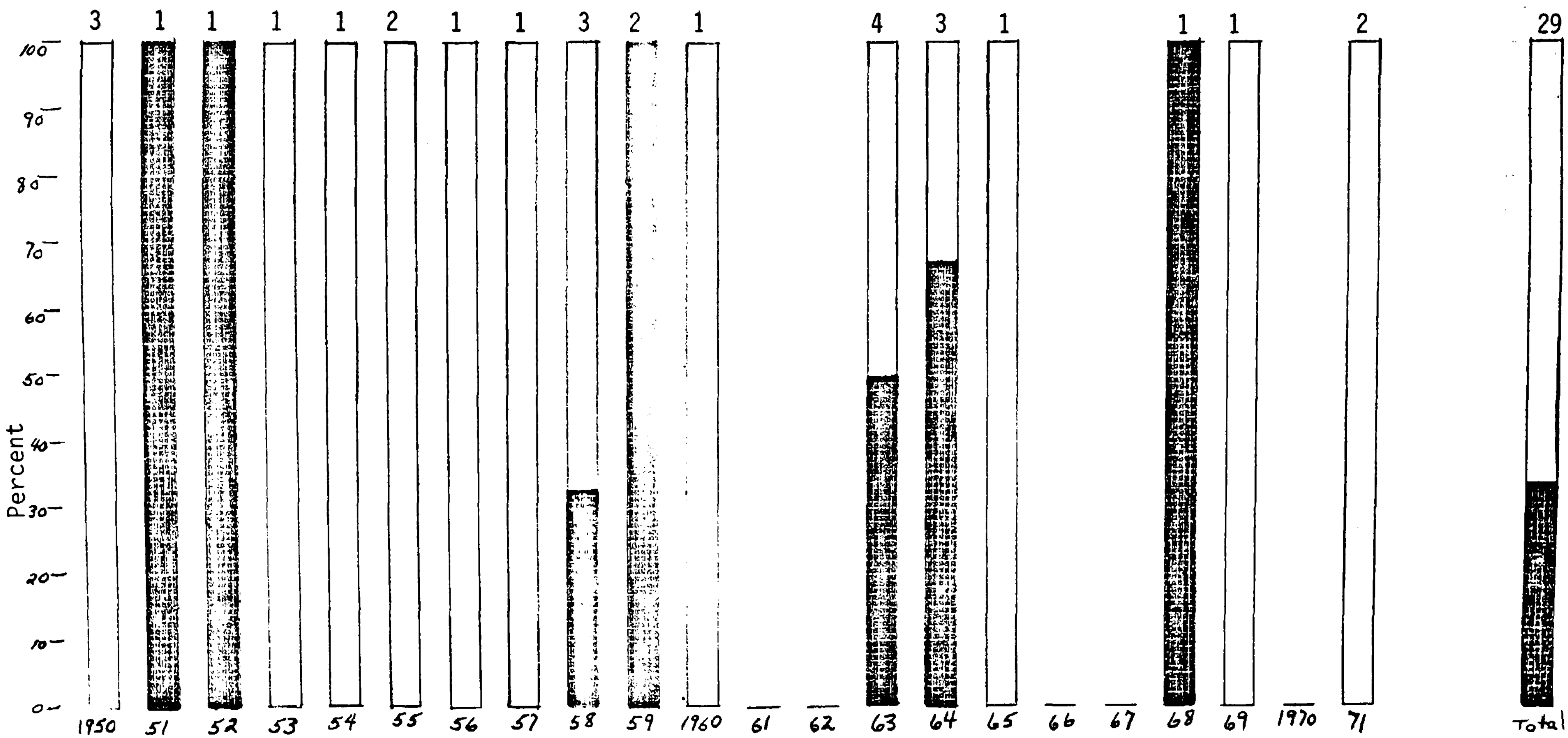
Sexual Differentiation - Asthma Deaths

(Number at top of bar indicates number of cases.)

Female

Male

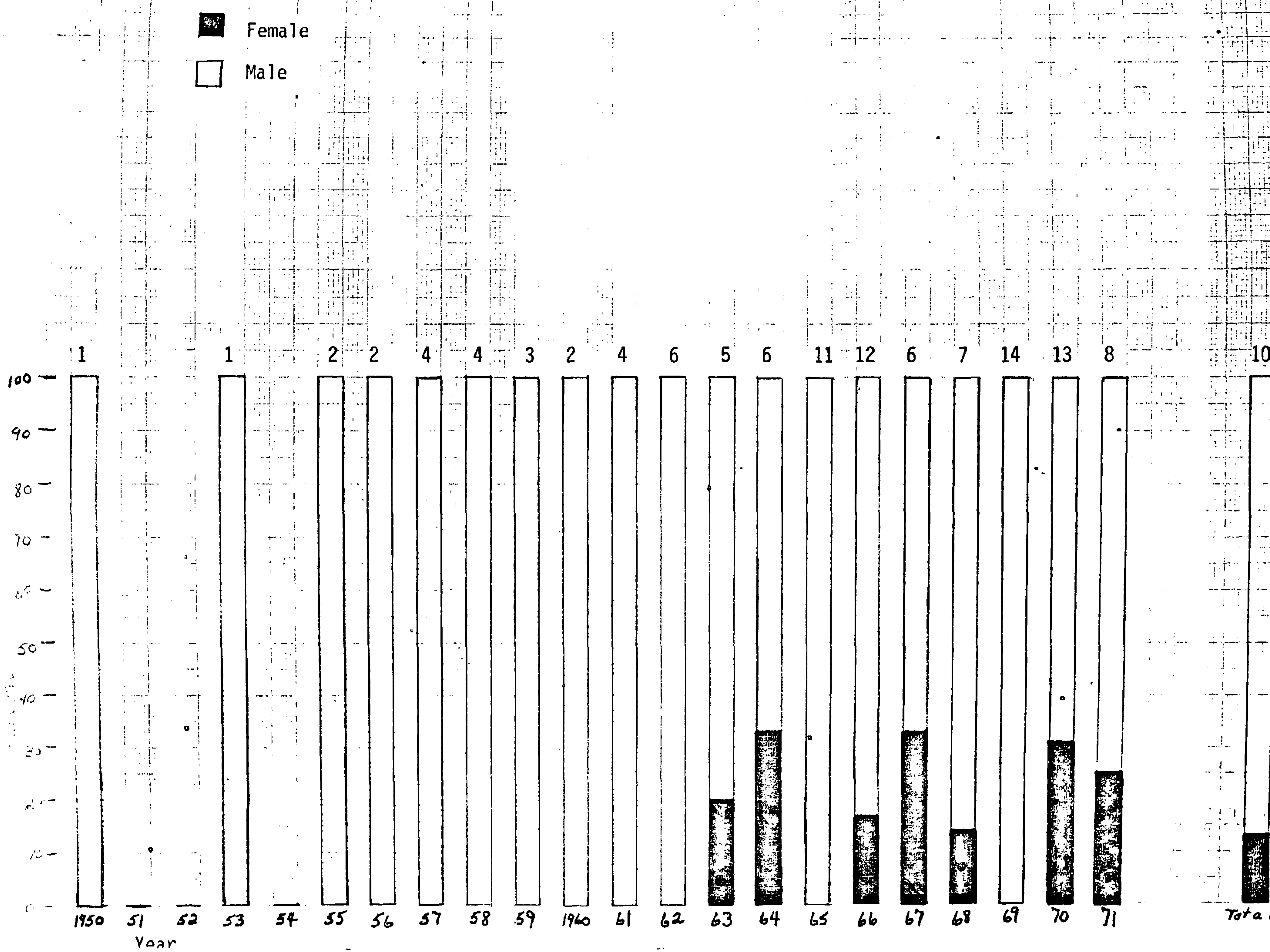
Figure 2.52



Sexual Differentiation - Emphysema Deaths

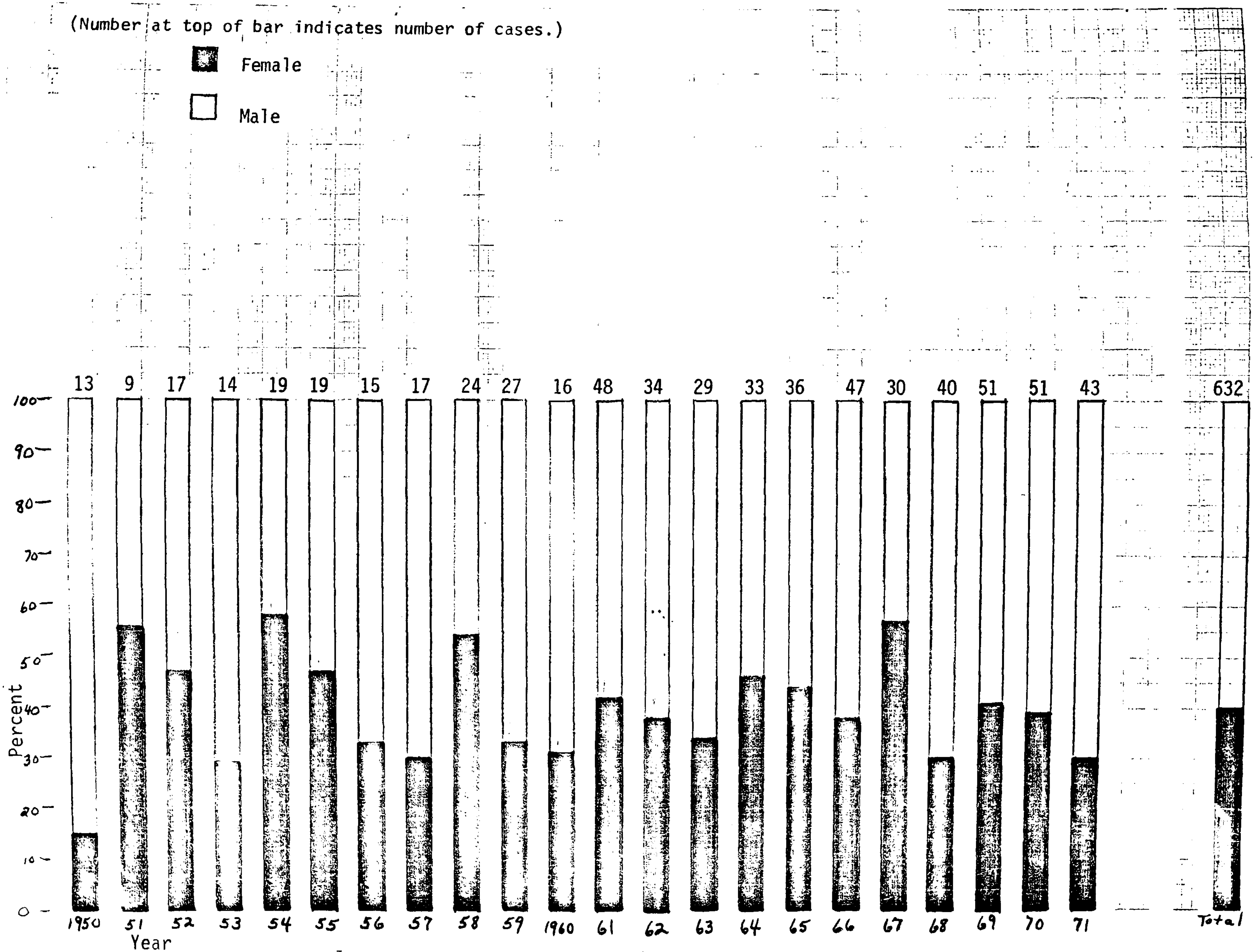
Figure 2.53

(Number at top of bar indicates number of cases.)



Sexual Differentiation - Pneumonia

Figure 2.54



AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF DEATHS
1950	23	0	0	0	0	8	8	15	46	13
1951	22	0	0	0	0	0	0	0	78	9
1952	6	0	0	0	0	6	0	12	76	17
1953	7	0	0	0	0	14	0	21	57	14
1954	10	0	0	0	0	16	16	10	47	19
1955	10	0	0	0	10	5	5	5	63	19
1956	20	0	0	0	7	13	13	7	40	15
1957	6	6	0	6	0	0	12	18	53	17
1958	25	0	0	0	0	12	4	17	42	24
1959	18	0	0	0	0	0	4	7	70	27
1960	19	0	0	0	0	0	6	19	56	16
1961	21	0	0	0	0	4	4	14	56	48
1962	18	0	0	0	3	0	0	15	65	34
1963	10	0	0	0	3	0	0	3	83	29
1964	0	0	0	0	3	6	9	6	76	33
1965	11	0	3	0	0	0	6	3	78	36
1966	4	0	0	0	2	6	8	11	68	47
1967	17	0	0	0	0	0	0	7	77	30
1968	8	2	0	8	2	0	2	12	65	40
1969	6	0	4	4	2	4	10	6	65	51
1970	4	0	2	0	4	0	8	10	72	51
1971	9	0	0	2	0	2	9	19	58	43
TOTAL	11	0	1	1	2	4	6	11	65	632

Figure 2.55

Age Differentiation - Pneumonia Deaths

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF DEATHS
1950	0	0	0	0	0	0	33	0	67	3
1951	0	0	0	0	0	0	0	0	100	1
1952	0	0	0	0	0	0	0	0	100	1
1953	0	0	0	0	0	0	0	0	100	1
1954	0	0	0	0	0	0	100	0	0	1
1955	0	0	0	0	0	0	50	0	50	2
1956	0	0	0	0	0	0	100	0	0	1
1957	0	0	0	0	0	0	0	0	100	1
1958	0	0	0	0	0	33	0	33	33	3
1959	0	0	0	0	50	0	50	0	0	2
1960	0	0	0	0	0	0	100	0	0	1
1961	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	25	50	25	4
1964	0	0	0	0	0	0	0	0	100	3
1965	0	0	0	0	0	0	100	0	0	1
1966	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	100	0	0	1
1969	0	0	0	0	0	0	0	0	100	1
1970	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	50	0	50	0	2
TOTAL	0	0	0	0	3	7	31	14	45	29

Figure 2.56

Age Differentiation - Asthma Deaths

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF DEATHS
1950	0	0	0	0	0	0	100	0	0	1
1951	0	0	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0	0	0
1953	0	0	0	0	0	0	0	100	0	1
1954	0	0	0	0	0	0	0	0	0	0
1955	0	0	0	0	0	0	0	50	50	2
1956	0	0	0	0	0	50	0	0	50	2
1957	0	0	0	0	0	0	25	0	75	4
1958	0	0	0	0	0	0	25	25	50	4
1959	33	0	0	0	0	0	0	33	33	3
1960	0	0	0	0	0	0	0	0	100	2
1961	0	0	0	0	0	0	0	50	50	4
1962	0	0	0	0	0	0	0	67	33	6
1963	0	0	0	0	0	0	0	40	60	5
1964	0	0	0	0	0	0	0	50	50	6
1965	0	0	0	0	0	9	18	36	36	11
1966	0	0	0	0	8	0	8	25	58	12
1967	0	0	0	0	0	16	33	33	16	6
1968	0	0	0	0	0	0	14	14	71	7
1969	0	0	0	0	0	14	14	14	57	14
1970	0	0	0	0	0	0	31	8	62	13
1971	0	0	0	0	0	0	0	38	62	8
TOTAL	1	0	0	0	1	4	13	29	52	104

Figure 2.57

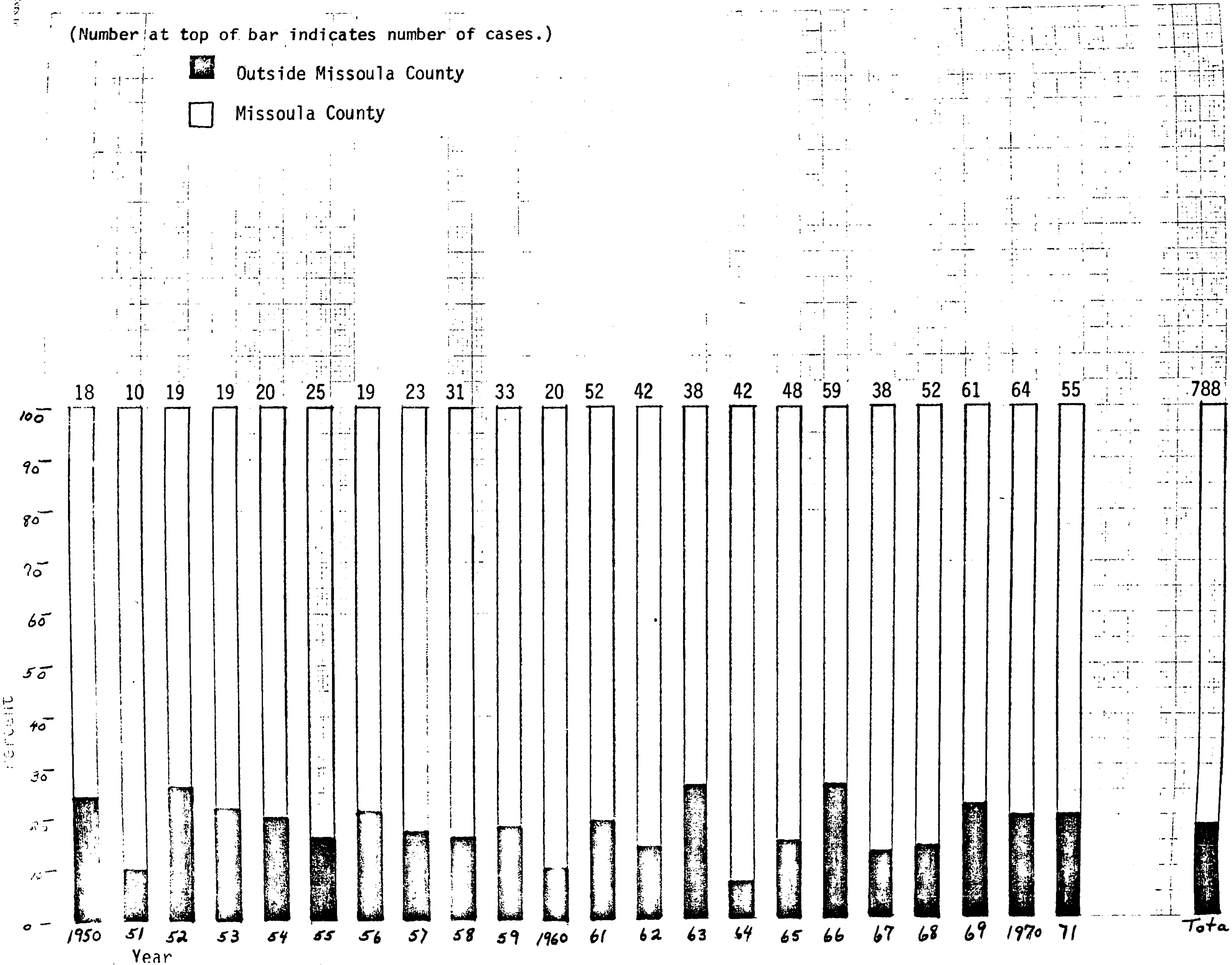
Age Differentiation - Emphysema Deaths

AGE GROUP (PERCENT)

YEAR	0-4	5-10	11-15	16-21	22-39	40-49	50-59	60-69	70+	NUMBER OF DEATHS
1950	17	0	0	0	6	6	17	11	44	18
1951	20	0	0	0	0	0	0	0	80	10
1952	5	0	0	0	0	5	0	10	79	19
1953	5	0	5	0	5	16	0	21	47	19
1954	10	0	0	0	0	15	20	10	45	20
1955	16	0	0	0	8	4	8	8	56	25
1956	16	0	0	0	5	16	21	5	37	19
1957	9	4	0	4	0	0	13	13	56	23
1958	19	0	0	0	0	13	6	19	42	31
1959	21	0	0	0	3	0	6	7	61	33
1960	15	0	0	0	0	0	10	20	55	20
1961	19	0	0	0	0	4	4	17	56	52
1962	14	0	0	0	2	0	0	21	62	42
1963	8	0	0	0	3	0	3	13	74	38
1964	0	0	0	0	2	5	7	12	74	42
1965	8	0	2	0	0	2	10	10	67	48
1966	3	0	0	0	3	5	8	14	66	59
1967	13	0	0	0	0	3	5	13	66	38
1968	6	2	0	6	4	0	8	13	62	52
1969	5	0	3	3	2	5	10	6	66	61
1970	3	0	2	0	3	0	12	9	70	64
1971	7	0	0	2	0	4	9	22	56	55
TOTAL	10	0	1	1	2	4	8	13	62	788

Figure 2.58

Age Differentiation - Combined Respiratory Deaths


(Number at top of bar indicates number of cases.)
Outside Missoula County
Missoula County
18 10 19 19 20 25 19 23 31 33 20 52 42 38 42 48 59 38 52 61 64 55 788
100 90 80 70 60 50 40 30 0
1950 51 52 53 54 55 56 57 58 59 1960 61 62 63 64 65 66 67 68 69 1970 71 Total
Year

Chapter Three

Summary and Conclusions

The Missoula Valley air pollution - respiratory disease study has been an ongoing project of the authors and the University of Montana Student Environmental Research Center for over two years. Most of that time was spent simply collecting and transcribing various data. This report represents the first publication resulting from the study. Detailed statistical analysis is presently continuing and updated research reports will be issued periodically. The Student Environmental Research Center eventually plans to publish a comprehensive monograph analyzing respiratory illness in the Missoula Valley.

In the first phase of this study the per capita, time series, admission rates to St. Patrick's Hospital for various respiratory illnesses were determined for the period from 1955 to 1971. Over 12000 respiratory admissions were analyzed. The per capita admission rates for chronic respiratory illnesses, particularly emphysema and chronic bronchitis, are increasing while the admission rates for acute respiratory diseases are constant or decreasing.

Some of the factors affecting the annual respiratory admission rates were also studied. Through statistical analysis it was determined that the mean annual temperature is negatively correlated with the annual hospital admission rate for various respiratory illnesses, particularly bronchitis, acute upper respiratory infection, and pneumonia. This inverse correlation indicates that a low (cold) mean annual temperature is associated with a high respiratory disease admission rate.

(The colder the mean annual temperature, the higher the respiratory disease admission rate.) Reduced visibility at the Missoula County Airport is also directly correlated with hospital admissions for respiratory illness, especially acute upper respiratory infection. This direct correlation implies that a high number of hours per year with visibility six miles or less at the Missoula County Airport due to smoke, fog,or haze is associated with a high annual admission rate for acute upper respiratory infection. (The poorer the visibility, the higher the acute upper respiratory infection admission rate.) With the exception of acute upper respiratory infection, the correlation between reduced visibility and respiratory admissions is not as strong as the correlation between mean annual temperature and respiratory admissions. However, the strongest correlation found in the study was between the annual number of hospital admissions for acute upper respiratory infection and the annual number of hours per year with visibility six miles or less due to smoke, fog, or haze at the Missoula County Airport. This correlation is particularly interesting since visibility reduction due to smoke or haze is caused by suspended particulate matter. It has also been shown that reduced visibility due to smoke or haze is associated with elevated particulate air pollution levels downtown at the courthouse.[3] Inversion conditions are also strongly linked with reduced visibility at the airport.

In an attempt to further study the factors affecting the hospital admission rate for acute upper respiratory infection, the statistical correlations between the monthly admission rate for acute upper respiratory infection and a number of environmental parameters were determined. The highest correlation found was with the average monthly particulate level at the Missoula County Courthouse. The negative correlation with the mean monthly temperature ranked second. The monthly correlations, although less strong than the annual correlations, tend to confirm the trends established with the annual admission correlations.

In the second segment of this study the mortality rates for various respiratory diseases in Missoula County were determined. The annual mortality rates for emphysema and pneumonia in Missoula County are increasing. The emphysema rate essentially parallels the National average; the pneumonia rate does not.

Certainly the most puzzling aspect of the study to date is the Missoula County pneumonia death rate. The pneumonia death rate has increased dramatically since 1950. The mean Missoula County death rate for pneumonia for the period 1950 through 1960 is 41 deaths per 100,000 population per year The 1961 - 1971 mean pneumonia death rate is 78 deaths per 100000 per year. This increase is statistically significant at the .001 level This mortality rate is far above the National average. The Missoula County rate may not be comparable to the National average, however. About 20 percent of the pneumonia deaths listed in the Missoula County death indices were not Missoula County residents. Also about two-thirds of the pneumonia deaths had multiple causes of death listed in the death indices. Both of these factors have remained essentially constant during the period of increase. The National death rate for pneumonia also does not include newborn deaths; however this factor is extremely small.

No statistical correlations have yet been attempted between

Missoula County respiratory mortality rates and various environmental parameters. All we know to date is that " something has happened." The per capita number of deaths with pneumonia listed as a cause of death in the Missoula County death index is increasing and this increase is statistically significant.

It is easy to speculate about the cause or causes of this increase. Speculation probably centers on air pollution. Missoula's air pollution problems have been noted and are well known. Numerous other possible causes could also be noted. While air pollution may not be responsible for or associated with the increase, the possibility certainly cannot be excluded or ignored.

Based on our research to date, we can see two major areas where future research must be conducted. The Missoula County pneumonia death rate must be studied and analyzed in detail; the increase in the death rate is too significant to ignore or leave unexplained. Secondly, a real time, longitudinal study of acute upper respiratory infection must be undertaken. Hospital admissions for acute upper respiratory are only the " tip of the iceberg " They are not a true measure of the incidence of the disease. However, since hospital admissions for acute upper respiratory infection are strongly associated with reduced visibility and hence with particulate air pollution and inversion conditions, the relationship between the disease and air pollution should be explored further. Physician's visits for acute upper respiratory infection will give a larger data base and a closer time link between the onset of the disease and entry into the data collection system. SERC is presently exploring the possibility of modifing the existing Physician's study to focus on acute upper respiratory infection.

References

1. Missoula County population data were obtained from the University of Montana Bureau of Business and Economic Research. The 1971 Missoula County population estimate was extrapolated from previous data.

2. The International Statistical Classification of Diseases, Injuries, and Causes of Death is the Standard medical record code. It is designed to provide a standard diagnosis so that " incidence" may be comparable. The code is revised periodically. Three code revisions took place during the time period of this study. Revisions were made in 1955, 1963, and 1969.

3. For a more detailed discussion of visibility reduction at the Missoula County Airport and its association with particulate air pollution see SERC Environmental Monograph #1, Climatic Modification and Air Pollution Prediction in the Missoula Valley.

4. The calculation and significance of the monthly inversion index is also described in Monograph #1.

5. In addition to death certificates, the Missoula County Clerk and Recorder's Office records each death in a "death index"

6. The National averages for the various causes of death were obtained from the Monthly Vital Statistics Reports , National Center for Health Statistics, Rockville, Maryland.